PETROLOGY AND VOLCANIC STRATIGRAPHY OF THE

EL SUECO AREA, CHIHUAHUA, MEXICO

APPROVED:

PETROLOGY AND VOLCANIC STRATIGRAPHY OF THE EL SUECO AREA, CHIHUAHUA, MEXICO

by

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THESIS

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Frontispiece. View west toward Sierra Gallego. The two thick flows of the Gallego rhyolite form prominent benches on the hillside.

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ABSTRACT

Detailed mapping of a 2000 km^2 area approximately midway between El Paso and Chihuahua City has delineated a greater than 1000 m section of rhyolitic, andesitic, and basaltic lava flows and rhyolitic ash-flow tuffs unconformably overlying Lower Cretaceous limestone. The area is dominated by large, NNW-trending fault-bounded mountains separated by bolsons.

The volcanic section can be compositionally and texturally divided into four sequences:

1. A thick sequence of ash-flow tuffs and related volcaniclastic sediments lie over an erosional surface on Cretaceous limestone. These deposits comprise the Liebres formation, the first sequence.

2. Voluminous flows of the Rancho El Agate tholeiitic andesite, a crystal-rich unit which has a source in the map area, make up the second sequence.
3. Lava flows, plugs, flow domes, sills and minor ash-flow tuffs of the Gallego, Carneros, El Dos, and Mesteño rhyolites make up the third sequence of volcanic activity. Some of these rhyolite bodies domed the adjoining rocks.
4. Basalt and minor interlayered ash-flow tuffs comprise the fourth sequence.

Chemical analyses indicate basaltic rocks of the area are metaluminous, and andesitic and rhyolitic rocks are peraluminous. A plot of alkalinity against silica indicates the rocks are gradational between the dominantly peraluminous rocks of the Sierra Madre Occidental and the metaluminous portion of the dominantly peralkaline rocks of Trans-Pecos Texas.

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INTRODUCTION

Geologic Setting

The rocks of this study belong to a band of Late Mesozoic and Cenozoic calc-alkaline igneous rocks that extends from Alaska and Canada through the western United States and Mexico and along western Central and South America to southern Chile. The average width of the belt is approximately 500 km, except in the western United States where it is as great as 1500 km (Lipman and others, 1972). The continuation of the belt south of this bulge includes the western half of the Basins and Ranges, the Upland with Basins, and the Sierra Madre Occidental physiographic provinces of Mexico (Fig. 1).

Regional Physiography

General Statement

Raisz (1964) and Hawley (1969) both recognize three major physiographic divisions in western and central Chihuahua. They agree on the general position of the Sierra Madre Occidental and the Basins and Ranges provinces. Their only major difference is in the classification of a central area with physiographic characteristics of both provinces. Raisz has designated it as an eastern subprovince of the Sierre Madre Occidental, the Upland with Basins. Hawley has portrayed the area as a western part of the Basin and Range province, the Babicora-Bustillos Subsection. Because studies by Mauger (1975) and Spruill (1976) appear to have shown the rocks to be more geologically related to those of the Sierra Madre Occidental than to the Basin and Range province, this report will use the physiographic divisions of Raisz.

Sierra Madre Occidental

The Sierra Madre Occidental contains the most extensive ignimbrite field in the world (125,000 km^2), comparable to the original extent of the now-disrupted mid-Tertiary ignimbrites of the Basin and Range province (Mauger, 1975). In the Sierra Madre Occidental these disturbed, dominantly rhyolitic ash-flow tuffs with minor intermediate and mafic volcanic rocks overlie a thick sequence of strongly-faulted and tilted andesitic rocks (Clabaugh, 1975).

Upland with Basins

The Upland with Basins province is 1200 km long, less than 150 km wide, and characterized by high mountain ranges with high-level bolsons between them. The mountain crests in this province are almost as high as those of the Sierra Madre Occidental. Spruill (1976) and Mauger (1975) have shown the area around Majalca to be a mixture of faulted, slightly metamorphosed felsic and andesitic rocks, overlain by felsic ash-flow tuffs. Along with major regional uplift, the rocks have experienced major normal faulting. The eastern border of the province is in most places marked by large escarpments.

Basin and Range

The Basin and Range province, in which the study area is located, is over 300 km long, covering parts of Sonora, Durango and most of Chihuahua, the largest state in Mexico. It trends northwest, as do most of the physiographic provinces of northern Mexico, merging to the north with the Basin and Range province of the United States and bordered on the south by the Cross Range. The region is characterized by large, NNW-trending fault-bounded mountains of Cretaceous carbonate and Tertiary volcanic rocks separated by broad, flat bolsons. The Cretaceous carbonate rocks have been subjected to both Laramide folding and thrusting and Tertiary normal faulting. Structure in the igneous rocks is generally limited to normal faulting.

Local Physiography

The fault-bounded mountains of the map area are strongly dissected and have relief of greater than 1200 m (4000 ft.). The highest point in the area, at 2457 m above sea level, is atop Cerro Gallego, 10 km southeast of El Sueco. The lowest point, at about 1230 m, is in the bolson near Rancho El Mesteño. The elevation of both ranges and bolsons decreases to the south.

Drainage in the area is to interior basins. East-west-trending streams and gullies supply run-off to three ephemeral lakes in or near the map area: Laguna Tarabillas, in the northern part, Laguna Encinillas, in the southwest, and Laguna Del Cuervo, in the south.

The area shows typical desert landforms, with large pediments sloping off the steep fault scarps. Preferential erosion of the softer formations, especially the unwelded zones of ash-flow tuffs and some of the agglomerates, have formed valleys and depressions between the more resistant units.

Previous Work

No detailed study of the volcanic rocks in the El Sueco area had been made prior to this report. Regional geologic maps depict the igneous rocks as undifferentiated Tertiary volcanic rocks. Figure 3 shows two major areas where detailed geologic studies have been made. Less than 160 km to the east of the map area a belt along the Chihuahua-Texas border has been studied largely by University of Texas graduate students working under the direction of Professor R. K. DeFord. DeFord (1964, pp. 116-129) and Underwood (1962, pp. 18-24) have written excellent summaries of this work. The other study, 650 km to the southwest of El Sueco, involved mapping of a narrow belt of volcanic rocks across the Sierra Madre Occidental. If extrapolated northwestward along the trend of the high volcanic plateau, this previous mapping would correspond to an area less than 150 km west of El Sueco. The southern trans-Sierra project has been conducted by graduate students of the University of Texas working chiefly under the direction of S. E. Clabaugh and F. W. McDowell. Its three major achievements have been:

1. Geologic mapping and geochemical and isotopic study of a transect across the Sierra Madre Occidental.
2. Recognition of a lower and upper sequence of volcanic rocks.
3. Demarcation of a large caldera complex near Durango.

A related accomplishment was the reconnaissance mapping and geochronology of the batholithic complex in Sinaloa (Henry, 1975; and Frederikson, 1974). Wahl (1973, pp. 14-17) gave a comprehensive review of geology done in the area through 1972. Swanson and others (in press), and McDowell and Keizer (in press), provide recent overviews.

Current Work

Mapping and study of volcanic rocks is presently being conducted around Majalca, about 50 km to the south of the map area (Fig. 1), by Dr. R. Mauger and graduate students of East Carolina University. The Instituto Nacional de Energia Nuclear, presently developing uranium deposits about 45 km south of the map area, has mapped an area of about 150 km^2 around the deposits (Fig. 1). Eric Swanson and Tim Duex of The University of Texas are mapping areas near Cuauhtémoc, Chihuahua (Fig. 1). The dissertation of Peter Keller is a companion study to this report and will include K-Ar dating of some of the volcanic rocks.

Purpose and Method of Investigation

The anomalous width of the belt of calc-alkaline volcanic rocks in the western United States has caused considerable disagreement and confusion over the petrogenesis of these rocks and their relation to plate tectonics. Northwestern Mexico seems to have a simpler, more characteristic belt of calc-alkaline rocks than the western United States and is therefore better for study and for the testing of petrogenetic models. Study of the Mexican belt should give insight into the complexities of the situation in the western United States. Toward this end, a group from the University of Texas at Austin has begun to acquire field and laboratory data from northwest Mexico. The project includes detailed mapping, geochemical, and isotopic work on a cross-section through the Sierra Madre Occidental volcanic province and comparison of the Mexican rocks to those in West Texas. The volcanic rocks of the Sierra Madre Occidental are predominantly peraluminous, whereas the igneous rocks of Trans-Pecos Texas are dominantly peralkaline (Barker, 1975 and in press; Maxwell and others, 1967). Yet unknown is the province to which volcanic rocks lying east of the Sierra Madre Occidental in Mexico belong (including those of the El Sueco area), and the nature of the boundary between the two igneous provinces. Mapping, geochemistry, and isotopic work has already been completed on a strip from Mazatlán to Durango City (see Fig. 1). If this strip is extrapolated northward along the trend of the

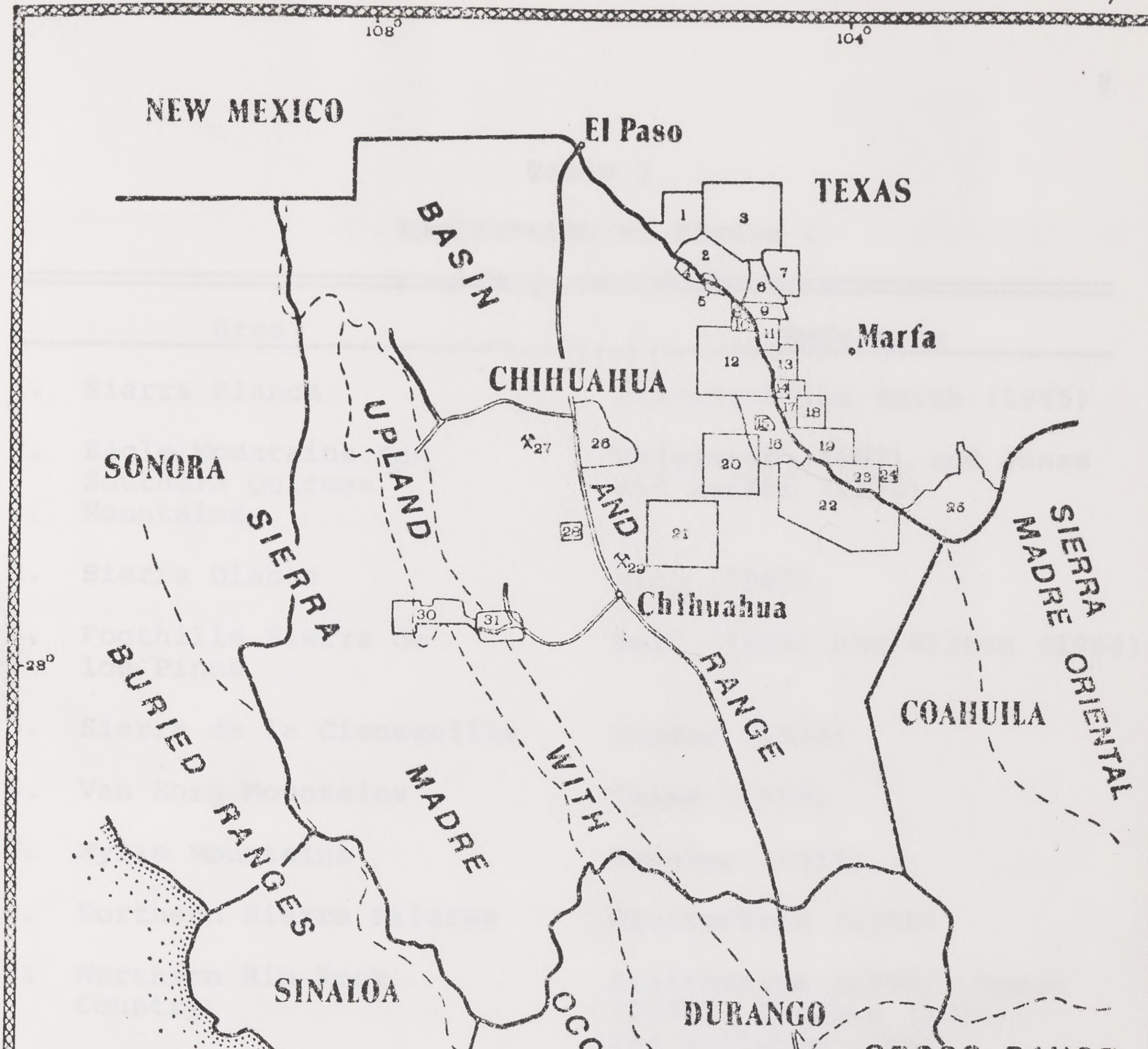


Figure 1. Location map showing areas studied near the map area and in the Sierra Madre Occidental, and the physiographic provinces of the region.

Table 1

Explanation of Figure 1

Area	Reference
1. Sierra Blanca	Albritton and Smith (1965)
2. Eagle Mountains and Southern Quitman Mountains	Underwood (1962) and Jones and Reaser (1970)
3. Sierra Diablo	King (1965)
4. Foothills Sierra de los Pinos	Bell (1964) and Milton (1964)
5. Sierra de la Cieneguilla	Reaser (1974)
6. Van Horn Mountains	Twiss (1959)
7. Wylie Mountains	Hay-Roe (1958)
8. Northern Sierra Pilares	Clutterbuck (1958)
9. Northern Rim Rock Country	Braithwaite (1958), Dasch (1958), Bridges (1958), and Wolleben (1966)
10. Central Sierra Pilares	Harwell (1959)
11. Porvenir	Bilbrey (1957) and Colton (1957)
12. El Cuervo	Haenggi (1966)
13. Candelaria	Buongiorno (1955) and Twiss and DeFord (1970)
14. Hot Springs	Dickerson (1966)
15. Cerro Prietos	Heiken (1966)
16. Sierra de la Parra	Gries (1970)
17. Pinto Canyon	Amsbury (1957)
18. Chinati Peak	Rix (1953) and Cepeda (in progress

Table 1 -- Continued

Area	Reference
19. Presidio	Dietrich (1965)
20. Cuchillo Parado	King and Adkins (1946)
21. Placer de Guadalupe	King and Adkins (1946)
22. Ojinaga-San Carlos	Burrows (1910) and Wolleben (1966)
23. Bofecillos Mountains	McKnight (1968)
24. Solitario Region	Sellards and others (1933) and Lonsdale (1940)
25. Big Bend National Park	Maxwell, Lonsdale, Hazzard and Wilson (1967)
26. El Sueco-Sierra Gallego Area	Bockoven-this report, and Keller (dissertation, in progress)
27. Terrenates Manganese Mine and Sierra de la Mojina	McAnulty (1969), Bridges (1962, and 1964), Denison and others (1970)
28. Majalca Area	Mauger (1975) and Spruill (1976)
29. Sierra Peña Blanca Uranium Mine	Instituto Nacional de Energia Nuclear (unpublished)
30. Tomochic	Swanson (dissertation in progress)
31. Cuahtémoc	Duex (dissertation in progress)
32. Mazatlan	Frederikson (1974) and Henry (1975)
33. Barranca and Navios-Tepalcates Areas	Waitt (1970)
34. El Salto Strip	Wahl (1973)
35. Durango Area	Keizer (1973) and Swanson (1974)
36. Cerro de Mercado	Lyons (1975)

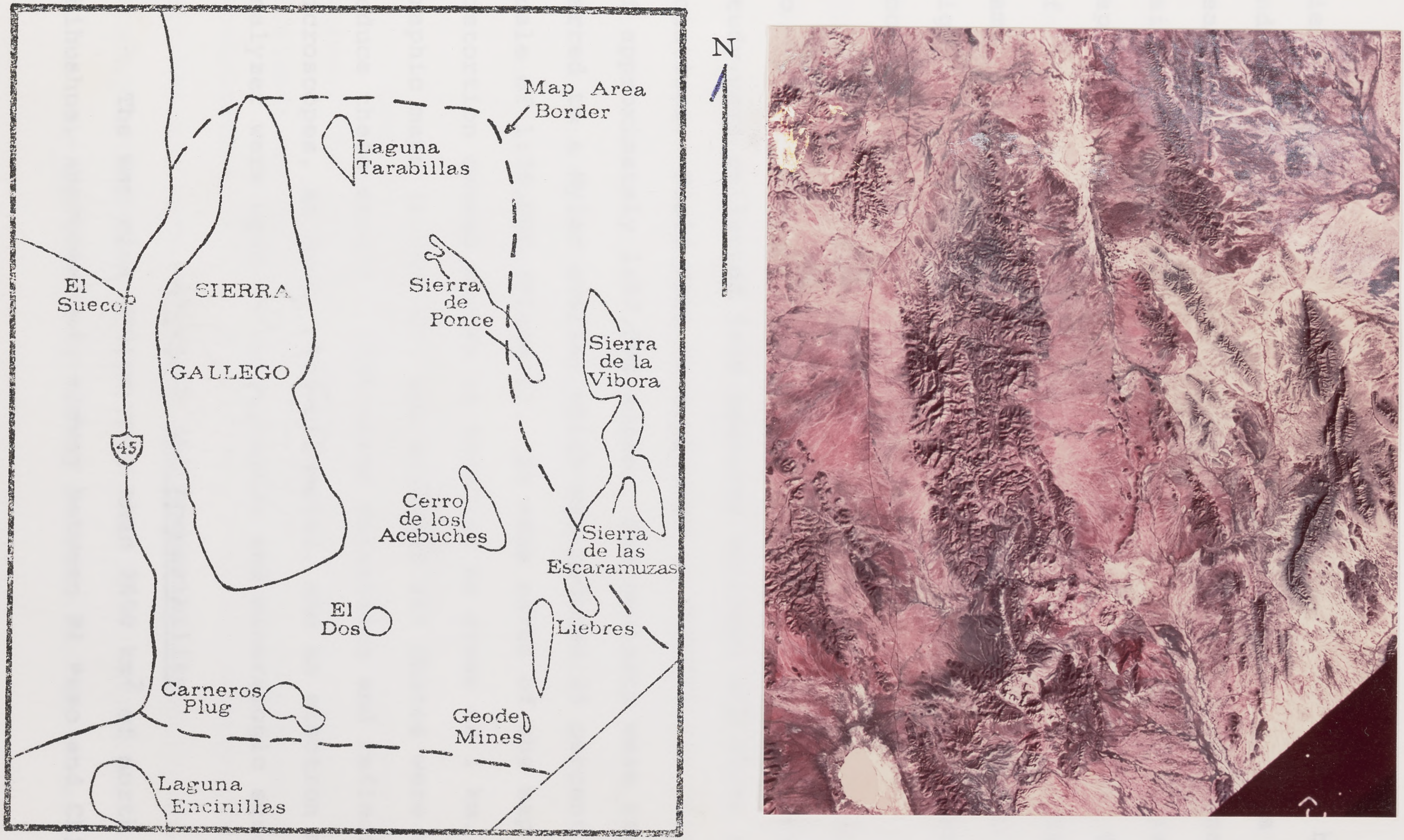


Figure 2. Skylab photograph (1:500,000) of map area with some features outlined.

Sierra Madre Occidental province, a 300 km gap exists between it and mapping done in West Texas. In the center of this gap, near El Sueco, Keller and I have mapped a 2000 km^2 area in detail (Fig. 1 and 2). Keller is doing further reconnaissance mapping to the west and south, has performed chemical analyses of fifteen rocks, and has made ten K-Ar age-determinations on samples from the area. These geochemical and isotopic investigations are based on the field and petrographic relationships documented here.

Mapping was conducted intermittently from October, 1975 to January, 1976. During this time samples for laboratory study were collected from measured sections and other relevant locations. Field data were plotted on CETENAL air photographs of approximately 1:57,000 scale. The contacts were transferred to a Mylar overlay which was reduced 25 percent to a scale of 1:76,000 (Plate 1). In some parts of the map photo distortion caused errors in location as great as 1 km. Topographic maps (1:250,000) and adjacent air photos were used to reduce these errors. Flat-stage polarizing and reflecting microscopes, an X-ray diffractometer, and an electron microanalyzer were used in petrographic and mineralogic study.

<u>Location and Accessibility</u>

The map area covers more than 2000 km^2 of north central Chihuahua, approximately midway between El Paso and Chihuahua

City at 29°45' latitude and 106°15' longitude (Fig. 1). The area is roughly triangular in outline; Mexican National Highway 45 forms the western border from just north of El Sueco (where Highway 10 branches to the west) south almost to Laguna Encinillas. The eastern border of the area is marked by the limestone ranges of Sierra de las Damas, Sierra de las Escaramuzas, and Sierra de Ponce.

Two unimproved dirt roads, one north of El Sueco, the other 27 km south of El Sueco leading into Rancho Gregoria and Ejido Esperanza, provided the only entryways into the area. A network of poor dirt roads connects Esperanza and the ranches of the area; some of the main roads are bulldozed after the rainy season. Several of the roads, for example the one continuing east of Ejido Esperanza, are blocked by gates. Patience and knowledge of Spanish are indispensable for obtaining keys at nearby residences.

Climate and Vegetation

Central Chihuahua is marked by desert climate and vegetation. The area is situated in the scarce rainfall province of Alemán and Garcia (1974, p. 188), with an average annual precipitation of 23 cm. The annual amount is highly variable, with the greatest amount of precipitation occurring during afternoons in the summer season. In 1974, approximately 30 cm. of rain fell on the area in a period of three days. Many roads were washed out and some cattle drowned (Quevedo, 1975, personal communication). Temperatures during June, July and August are extreme, with daily highs usually exceeding 100° F.

The best months for field work are September through December. March, April and May are suitable but the region is very dry and dust storms are common. Afternoon rainstorms, road washouts, snakes, and 100° F temperatures make summer field work impractical, if not impossible.

Vegetation includes grasses, century plants, yuccas, mesquite, and many varieties of cacti. Rows of cottonwoods are found along the small creeks in the area.

Terminology

Terminology applied to pyroclastic rocks in this thesis conforms to that of United States Geological Survey literature (Smith, 1960; Ross and Smith, 1961). Ash-flow tuffs are named using the component triangle of Cook (1965). Volcanic rocks are classified according to composition using weight percent oxides (Middlemost, 1972), and by normative mineralogy according to Irvine and Baragar (1971). Color descriptions correspond to those of the Geologic Society of America Color Chart (Goddard and others, 1951). The names assigned to rock units in this thesis are informal.

STRATIGRAPHY AND PETROGRAPHY

A composite section of over 1200 m of basaltic, andesitic, and rhyolitic flows, rhyolitic ash-flow tuffs and related rocks is exposed in the map area (Fig. 3). The volcanic section is divided into four sequences. The oldest sequence is a series of ash-flow tuffs; the second is a series of intermediate to mafic lava flows; the third is a voluminous series of rhyolitic lava flows; and the youngest sequence is made up of basalt flows with minor interbedded rhyolite ash-flow tuffs. Overlying an erosional surface on folded Cretaceous limestone is a thick sequence of ash-flow tuffs and related volcaniclastic sediments which comprise the Liebres formation. The Liebres formation is overlain by a sill (?) of the Mesteño rhyolite, a crystal-poor, flow-layered rock belonging to rocks higher in the section. Three members of the Mesteño rhyolite have tentatively been recognized: a lava flow, a sill (?), and a group of flow domes. Resting on the Mesteño rhyolite sill (?) is the Rancho El Agate tholeiitic andesite, a series of crystal-rich lava flows, which comprise the second sequence of volcanic rocks. The Rancho El Agate tholeiitic andesite is overlain by two massive flows of the Gallego rhyolite. The lava flow member of the Mesteño rhyolite lies above the Gallego rhyolite and is overlain by a white crystal-rich

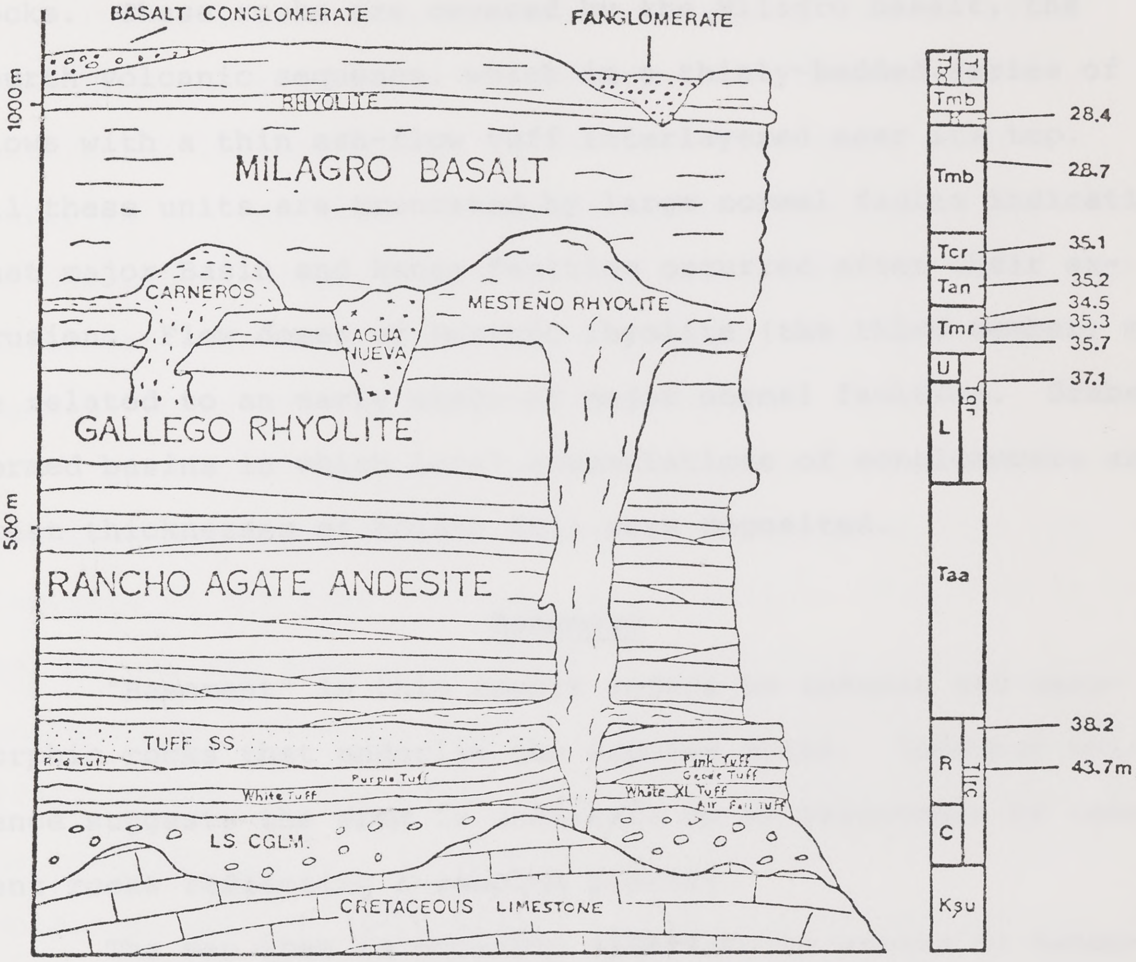


Figure 3. Composite section of the El Sueco-Sierra del Gallego area. Numbers at right refer to ages of unit. The top seven dates have errors of ± .6 m.y. The bottom three have errors of ∓ .8 m.y. Modified after Keller (in progress).

porphyry, the Carneros rhyolite. The Gallego, Mesteño, and Carneros rhyolites comprise the third sequence of volcanic rocks. These rocks are covered by the Milagro basalt, the fourth volcanic sequence, which is a thinly-bedded series of flows with a thin ash-flow tuff interlayered near its top. All these units are truncated by large normal faults indicating that major Basin and Range faulting occurred after their extrusion. Flow domes of Mesteño rhyolite (the third member) may be related to an early stage of major normal faulting. Grabens formed basins in which local accumulations of conglomerate and great thicknesses of bolson fill were deposited.

Basement

"Basement" in this report refers to igneous and metamorphic rocks that underlie the exposed rocks. Indirect evidence suggests the area is underlain by an assortment of basement rocks reflecting a complex history.

The map area is probably underlain by stocks or batholiths of granitic rocks. Burrows (1910) described a granite intrusion at Chorreras, about 100 km southeast of the map area. Moreover, boulders of granite over half a meter in diameter were found less than 10 km west of the map area in a small, dry creek bed draining a hill of altered rhyolite. The boulders, which are probably xenoliths brought up by rhyolitic magma, are large enough to preclude extensive transport. Keller (dissertation in progress) will include this area in his reconnaissance mapping.

Other indirect evidence of underlying silicic rocks comes from the occurrence of "fritted" or "fingerprint-textured" feldspars in one of the lava flow units with a source in the map area. Numerous authors, including Al-Rawi and Carmichael (1967), Kuno (1950), and Sigurdsson (1971) have attributed this texture to the incorporation of crystals of granitic rocks in a rising basaltic magma.

In addition to the granitic rocks, older basement rocks including metarhyolite and schist have been found in a conglomerate at the base of Sierra de la Mojina, less than 50 km west of the map area (Fig. 1). Flow directions studied on the conglomerate indicate a source to the east-southwest (Bridges, 1964), toward the map area. Bridges (1962 and 1964) described the conglomerate as a thick-bedded to massive fluvial unit containing cobbles and boulders (30 cm or less in diameter) of quartzite, gneissic quartzite and schist, and lesser amounts of limestone, vein quartz, and rhyolite. Denison and others (1970) described boulders from the conglomerate including quartzofeldspathic and muscovite schist, rhyolite, and metahyolite. They describe the schists as having well-developed foliation and pronounced chevron folds. The metarhyolite exhibits sheared and recrystallized phenocrysts in a granoblastic groundmass. They interpret the rocks as regionally metamorphosed, with intense compression and deformation. Their fifteen Rb-Sr and five K-Ar determinations give a range in age from 187±6 for a rhyolite to 740±16 m.y. for a metarhyolite, with large clusters of ages around 250 and 700 m.y. ago. The data indicate:

> . . . the source for the boulders was an area in which Precambrian rhyolite was common. These rhyolites later underwent a regional metamorphic event in Permian time which changed them to their present character. Some unmetamorphosed rhyolites, most likely with a Permian age of extrusion, were also in the source area (Denison and others, 1970, p. 10).

Cretaceous Limestone

Large fault-bounded mountains of highly folded limestone mark the eastern boundary of the study area. The strata are shown on our map as undifferentiated limestone (Plate 1). Ammonites collected from limestone in the Sierra de las Damas were classified by Young (personal communication) as Albian (Lower Cretaceous). According to DeFord (1969), the carbonate strata of the Sierra de las Escaramuzas, Sierra de Ponce, and Sierra de las Damas formed at the western edge of the Chihuahua Trough. The remainder of the map area, upon which most of the volcanic rocks lie, was part of the Aldama Platform during Cretaceous time. The Chihuahua Trough was the site of thick Cretaceous deposits of carbonate rocks on Permian and Jurassic evaporitic rocks.

Liebres Formation

The Liebres formation, named for exposures at Liebres in the east central portion of the area, has the most diverse lithology of any unit mapped. The formation consists of a basal limestone conglomerate overlain by five extensive and many smaller ash-flow tuffs, with interbedded volcaniclastic sedimentary rocks and agglomerate. The units within the Liebres formation have been designated with letters, and a fence diagram of their distribution is shown in Figure 4. The limestone conglomerate, here labeled unit D, everywhere underlies the lowest pyroclastic sheets of the formation. The conglomerate, similar to the Jeff conglomerate to the east (McKnight, 1968), and to the Pozos Formation to the south (Alba and Chavez, 1974), is composed almost entirely of well-rounded cobbles and pebbles of cherty limestone and chert, with minor contributions of quartzose sandstone or quartzite cobbles and altered volcanic rock fragments. The limestone cobbles are in every discernable aspect similar to the Cretaceous limestone in the nearby ridges to the east. Haenggi (1966), in the El Cuervo area, and King and Adkins (1946) at Coyame and Placer de Guadalupe, described quartzose sandstone interbedded with limestone and shale in the Lower Cretaceous Las Vigas Formation. This may be the source of the cobbles of quartzose sandstone in the conglomerate. The conglomerate contains a moderately greater percentage of volcanic rock fragments in

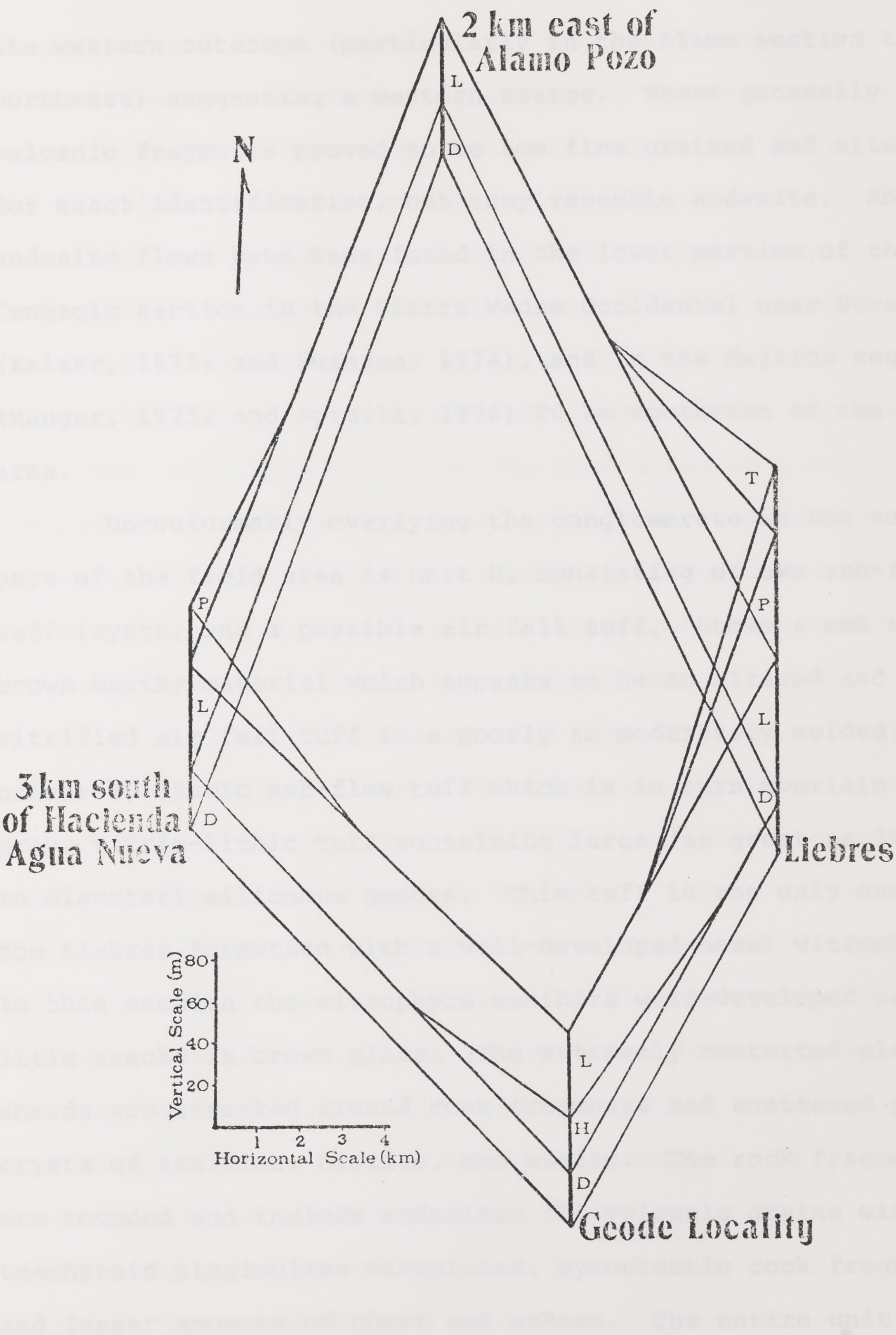


Figure 4. Fence diagram of units within the Liebres formation. Descriptions in text.

its western outcrops (particularly in the Alamo section to the northwest) suggesting a western source. These generally brown volcanic fragments proved to be too fine grained and altered for exact identification, but they resemble andesite. Abundant andesite flows have been found in the lower portion of the Cenozoic section in the Sierra Madre Occidental near Durango (Keizer, 1973; and Swanson, 1974), and in the Majalca region (Mauger, 1975; and Spruill, 1976) 20 km southwest of the map area.

Unconformably overlying the conglomerate in the southern part of the field area is unit H, consisting of two ash-flow tuff layers, and a possible air fall tuff. Above a red to brown earthy material which appears to be an altered and devitrified air fall tuff is a poorly to moderately welded, pale-red, vitric ash-flow tuff which is in turn overlain by a gray, vitric-lithic tuff containing large (as great as 30 cm in diameter) siliceous geodes. This tuff is the only one in the Liebres formation with a well-developed basal vitrophyre. In thin section the vitrophyre exhibits well-developed perlitic cracks in brown glass. The extremely contorted glass shards are streaked around rock fragments and scattered phenocrysts of sanidine, biotite, and augite. The rock fragments are rounded and include andesitic (?) volcanic grains with trachytoid plagioclase microlites, pyroclastic rock fragments, and lesser amounts of chert and arkose. The entire unit is strongly devitrified and altered. The black vitrophyre is about 1.5 m thick with equal thicknesses of clay above and below. This clay is actually opaline, bentonitic, devitrified and altered vitrophyre, and is the major productive zone for geode mining. The geodes are composed of chalcedony, quartz crystals (some amethyst), calcite, opal, hematite, and at least seven manganese oxide minerals (Finkelman and others, 1974). Groundwater probably moved along partings above and below the vitrophyre, allowing the alteration to proceed from both sides to produce the thick rind of clay. Partings are common in densely welded tuffs, usually following concentrations of eutaxitic pumice lapilli which have been preferentially weathered out (Lipman and others, 1966).

Directly overlying unit H in the southeast and the limestone conglomerate elsewhere, is a section of three closely-spaced, ridge-forming ash-flow and air-fall tuffs, approximately 40 meters thick designated unit L. These three tuffs are the most extensive in the map area, covering at least 600 km^2. The basal layer is the least welded and is absent in some outcrops. In many exposures it is thin-bedded, apparently having been reworked by water. Petrographically it is clearly a waterlain tuff, probably of air-fall origin. It contains approximately 15 percent pumice and as much as 25 percent crystals of anhedral to subhedral plagioclase, anorthoclase-sanidine, quartz paramorphs after beta quartz, and biotite.

The crystals average .25 mm in diameter. As would be expected, only thick, undeformed shards are present, and these exhibit axiolitic devitrification. Some pumice retains its structure, but a large proportion has been crushed and flattened. Flattened and unflattened pumice seen in the same thin section indicates the material was eroded from different units. Abundant zeolites comprise the cement.

The middle tuff of unit L is approximately 20 m thick and includes a ridge-forming, moderately-welded zone 5 m thick. It is a cream white (N9) vitric ash-flow tuff, containing no more than 7 percent phenocrysts of strongly resorbed quartz as large as 2 mm in diameter. The shards are highly devitrified and exhibit slight distortion. Granophyric crystallization is pronounced in the rock, and calcite has filled some pore space.

The upper tuff is approximately 10 m thick with a 5 m strongly-welded zone. It is a pale red-purple (5RP 6/2), vitric to vitric-crystal ash-flow tuff containing 5-12 percent phenocrysts of quartz paramorphs after beta quartz, and lesser amounts of somewhat chatoyant sanidine-anorthoclase, biotite, and zircon. The rock has amygdules of stretched pumice cavities lined with white carbonate minerals. Lithic fragments are not common; they include pyroclastic rocks and red-brown shale (?). The shards in this tuff are only slightly deformed with complete bubbles still present. Axiolitic devitrification is strongly developed in most of the shards.

The quartz paramorphs are subhedral, 5 mm in diameter, and deeply embayed (Fig. 5). The sanidine-anorthoclase is subhedral, .8 mm or less, and is at least partially chatoyant. Rosenquist (1965) and Laves and Soldatos (1963) showed that iridescent alkali feldspars have a cryptoperthitic structure consisting of either lamellae or flattened near ellipsoids of albite lying in the plane of iridescense. MacKenzie and Smith (1956) and Smith and MacKenzie (1958) have shown that members of the sanidine-anorthoclase optical series tend to be perthitic when their bulk Or content lies between Or_{60} and Or_{20}.

Although rubble and soil cover most of the area between welded zones, it is likely that the three layers are separate cooling units. Because the units are nearly always found together (in some places the lower tuff is absent) with little erosion of soft layers, and because they are so closely spaced, it is possible they were erupted from the same center, although no source for these ash flows is found in the map area.

Overlying unit L is unit P, a 65 m thick, moderately welded, reddish-brown (10 R 4/6) to grayish pink (5R 8/2) vitric-crystal tuff. The grayish pink tuff appears to be the "fresher" of the two varieties; the reddish-brown color is more common and appears to be a product of both denser welding and more alteration (of biotite) than the grayish pink. This unit has as much as 15 percent phenocrysts of resorbed, subhedral quartz paramorphs after beta quartz, and anhedral

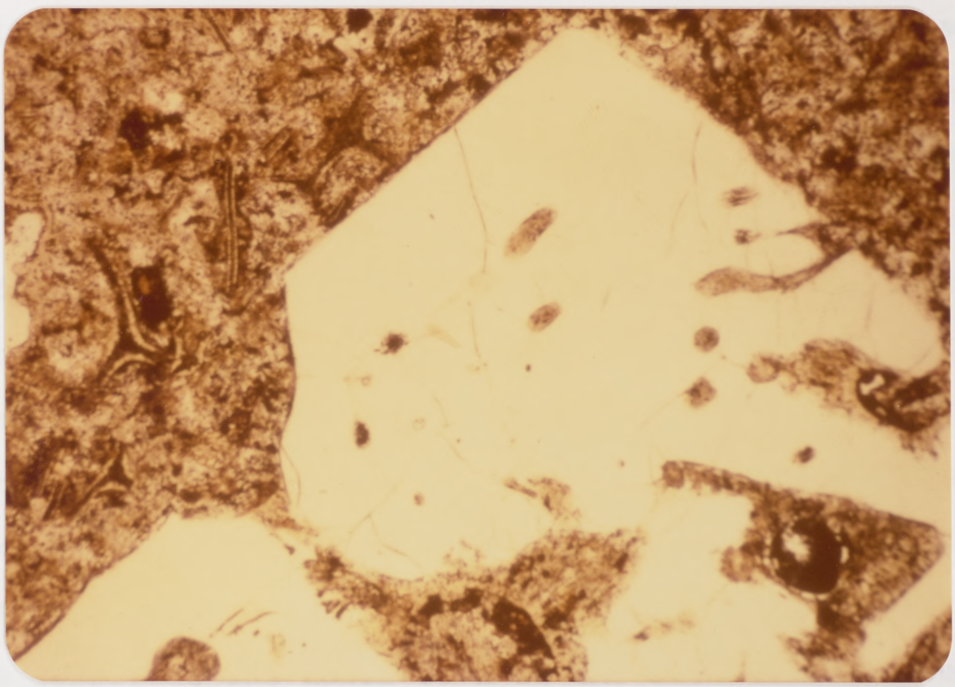


Figure 5. Photomicrograph (plane light) of Unit L of Liebres formation. Strongly resorbed quartz paramorph after beta quartz in a matrix of axiolitically devitrified shards and dust. Long dimension is 2.2 mm.

sanidine, with lesser amounts of subhedral, twinned and zoned plagioclase, fresh biotite, and zircon. The Michel-Lévy method for determination of plagioclase composition gave a maximum extinction angle of 16° on albite twins, corresponding to a sodic andesine composition. The reddish-brown tuff is moderately welded with slight deformation of the shards, most of which are highly devitrified. Some addition of calcite in the pore spaces and vugs has occurred. In some places the tuff has a large percentage of lithic fragments, including pieces of older pyroclastic units, trachytoid volcanic rocks, and chert. Near the top of the unit blocks of devitrified pumice greater than 1 m in diameter are encased in the tuff.

At Liebres a thick section of volcaniclastic sedimentary rocks and air fall tuffs, labeled unit T, overlies unit P. Poorly indurated, pale-green, finely bedded tuffaceous sandstone comprises the upper 50 m of the Liebres formation at its type locality. A cursory search yielded no fossils, but cross-bedding, ripple and load cast structures are locally abundant. Contained within this thickness of tuffaceous sandstone near its top is a 2-3 m thick lens of conglomerate composed of cobbles and boulders of, in decreasing abundance, limestone, chert, quartzite, and volcanic rock.

The Liebres formation at Liebres is almost 300 m thick. Elsewhere only portions of this section are found. Unit H is not found in the northern part of the map area. The eastern edge of the map roughly corresponds to the easternmost extent of the Liebres formation. To the west the formation is covered by overlying units and its westernmost extent is not known. Keller (in progress) has located outcrops of the Liebres formation several kilometers west of the map area, indicating the formation extends under Sierra Gallego and covers an area greater than 2000 km^2. A conservative estimate of the average thickness of the formation is 50 m. The amount of material represented by the formation is therefore estimated to be at least 100 km^3.

Mesteño Rhyolite

In most places the Liebres formation is overlain by the Mesteño rhyolite which is composed of two layers that are separated by other volcanic units. For the sake of brevity, the lower Mesteño member will be described with the upper one after the next two units are discussed.

Rancho El Agate Tholeiitic Andesite

Overlying the Liebres formation and the lower layer of the Mesteño rhyolite is a crystal-rich lava flow here named the Rancho El Agate tholeiitic andesite. The unit includes many individual flows, which now form successive benches on the hillsides. At least twelve of these bench-formers are present, with varying degrees of induration, columnar jointing, and thickness. The largest two flows are approximately 12 m thick and occur successively near the top of the unit. The flows are grayish red (10 R 4/2) except on chilled surfaces where they are grayish black (N2). Jointing, especially columnar, is pronounced, with the most prominent fracture surfaces striking northwest and dipping steeply to the west. This jointing causes talus piles to develop below most of the ridges. The unit is vesicular throughout, particularly at the top of the unit. In many places these vesicles are filled with chalcedony and agate. Amygdules are currently mined from the Rancho El Agate tholeiitic andesite, which has produced some of the finest agate in the world. More discussion of the agate mining can be found in the Mineral Deposits section of this thesis. Red and Brown jasper occurs in veins scattered throughout most of the flows. White chalcedony roses, which may be a pedogenic feature, are also common at the surface.

The Rancho El Agate tholeiitic andesite has the largest outcrop of any unit in the map area. At Rancho El Agate, on the eastern side of Sierra del Gallego (Plate 1), variations in regional trends of ridges, and the tremendous thickness of the unit indicate that this was a source area. At the ranch the base is not exposed but a partial thickness of more than 260 m has been measured (see Appendix for Measured Sections). A tall, well-jointed spine at the ranch is believed to be a volcanic neck. A measured section of the tholeiitic andesite nearly 15 km away from Rancho El Agate still total 250 m thick, which may indicate that there was more than one source area. Indeed, great thicknesses are present along the whole eastern margin of the map area (e.g., at Cerro Acebuche and north of Sierra de Ponce) as much as 25 km from the ranch, suggesting source areas to the east. Alternatively, the source at Rancho El Agate may have produced enough highly fluid lava to flow great distances and to fill in low areas where particularly thick sections are present. However, in the bolson of the central part of the map area, the unit is apparently much thinner, spottier in occurrence, and less layered than at Rancho El Agate.

The area covered by the Rancho El Agate tholeiitic andesite is at least 1000 km^2. The unit covers at least a third of the map area and has also been found to the west, northwest, and south. An approximate average thickness would probably be at least 100 meters. A conservative estimate would therefore place the amount of Rancho El Agate tholeiitic andesite at greater than 100 km^3.

In thin section the rock is hypo-to-holocrystalline with augite, hypersthene, and odd, fritted feldspar phenocrysts set in a matrix of alkali feldspar, pyroxene and glass. In more crystallized portions of the unit (e.g. near the source), tiny (.08 mm long), clear needles of apatite (?) occur throughout the rock. The augite is anhedral, commonly twinned, and averages 1 mm in diameter. Hypersthene is less common and averages 1 mm in length.

The rock is glomeroporphyritic with clusters of as many as 25 crystals. Tiny H-shaped microlites (.05-.1 mm) of plagioclase are common in the glass. Lofgren (1972a) produced identical growth shapes by quenching synthetic plagioclase melts. He analysed glass near the crystals and found that within 5-10 microns of the crystals the Ca content was 2-9 percent lower than that of the bulk melt. He attributed this to competition between the diffusion rate of Ca in the melt and the growth rate of Ca-plagioclase.

The "fritted" texture of the feldspars (Fig. 6) is due to dark blebs of glass and inclusions which honeycomb the interiors of the phenocrysts. Fritted phenocrysts are generally plagioclase but also include anorthoclase. The cores of most of these grains are unfritted; in some there is a thin, clean rim around the fritted portion of a grain. The blebs or tongues of glass do not appear to be oriented. In some of the phenocrysts, small augite grains have formed or lodged inside the fritted portion of the feldspar. Both the plagioclase and anorthoclase are zoned; the plagioclase exhibits strong oscillatory zoning, whereas anorthoclase zoning is patchy. Both feldspars are twinned; the plagioclase features albite and Carlsbad twinning, and the anorthoclase shows pericline and albite fine gridiron twinning. Plagioclase

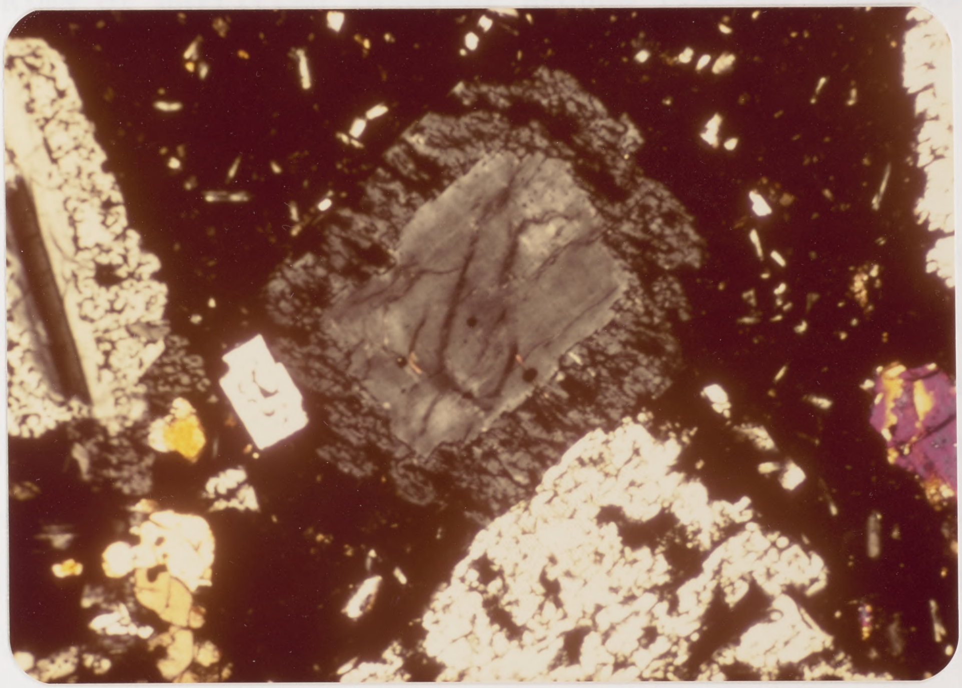


Figure 6. Photomicrograph (crossed-nicols) of the Rancho El Agate tholeiitic andesite. Fritted phenocrysts of plagioclase (center left) and anorthoclase (center) occur with augite (right center) in a glassy groundmass. Long dimension is 2.2 mm.

phenocrysts are subhedral, and as long as 5 mm, but average 2 mm. Anorthoclase phenocrysts are generally euhedral and average 1-2 mm. In thin sections containing abundant glass, fritted feldspars have either thin rims of unfritted feldspar, or no rims at all. Rims of unfritted feldspar around fritted cores are better developed in rocks that contain little or no glass. Rim formation, therefore, may be a late stage development that was arrested by quenching in the glass-rich rocks.

Fritted, or "fingerprint-textured" feldspars have been described previously by many geologists. The texture is significant as it records a process which has affected the chemistry and history of the rocks. Al-Rawi and Carmichael (1967) have described "spongy" or fingerprint-textured sodic plagioclase and alkali feldspar in a basaltic andesite at its contact with a granite. They suggest that the fritted feldspars are xenocrysts from the granite that have been partially assimilated and partially fused by the basaltic andesite. MacDonald and Katsura (1965) described fritted feldspars in a dacite at Lassen Peak, Cascade Range, California. As in the Rancho El Agate tholeiitic andesite, many of the Lassen Park fritted grains have solid centers and rims with fritted zones in between. Using the Rittman zonal method (Rittman, 1929), they determined that the fritted portions are significantly more calcic than the interiors of the grains, and have the same composition as microlites in the groundmass. They believe that these feldspars are "remnants of remelted granitic rocks of the underlying silicic basement admixed with basaltic magma rising from still greater depth" (MacDonald and Katsura, 1965, p. 475). Sigurdsson (1971), in studies of Gjafakollur Mountain in Iceland, has found fingerprint-textured feldspars he believes are the result of mixing of mafic and felsic magmas causing a "temporary fusion of oligoclase phenocrysts" in the granitic magma. His electron microprobe analyses indicated that the fritted feldspars are oligoclase with a thin rim of sodic anorthoclase. Unfritted phenocrysts of bytownite rimmed with oligoclase were also noted in the Icelandic rocks.

Kuno (1950) reported a similar "honey-combed" structure in plagioclase from the Hakone volcanic area in Japan. He attributed the texture to glass inclusions and dusts of clinopyroxene and iron oxide "which originated by partial crystallization of liquid particles formed by melting of xenocrystic plagioclase along its cleavages" (Kuno, 1950, p. 1015). Heiken (1966, p. 38) presented a photomicrograph of an andesite porphyry from his study area near Ojinaga, Mexico, which reveals a zoned and apparently fritted plagioclase phenocryst. Swanson (1974) mentions spongy-textured plagioclase with centers charged with glass blebs from a basalt near Durango. He also has described partially fused xenoliths in the same rock. It is significant that in all cases known to the author, the fritted grains occur in intermediate to mafic lava flow rocks. This observation is compatible with the theory of their formation.

Fritted texture is apparently common, especially in areas where mafic magmas have moved upward to the surface through granitic rocks. Incorporation of sodic plagioclase and probably other silicic components by mafic magmas may play a large role in affecting bulk rock chemical compositions in the El Sueco area and in other volcanic regions around the world.

Gallego Rhyolite

Directly overlying the Rancho El Agate tholeiitic andesite is the Gallego rhyolite. This unit is composed of two tremendous lava flow units; the lower one over 100 m in thickness, and the upper and less widespread one nearly 50 m thick (Frontispiece). All outcrops of the Gallego rhyolite are located west of the central bolson in the map area except one small hill approximately 8 km south of Sierra de Ponce and west of El Tule (Plate 1). This unit also extends beyond the study area to the west, northwest, and south. Such thicknesses of rhyolite flows over such an extensive area are uncommon. Rhyolite lavas are usually either too viscous or too explosive during eruption (producing pyroclastic flows) to cover extensive areas by flow.

The Gallego rhyolite is pale-brown (5 YR 5/2) to gray (N5) with large white phenocrysts, and is typically altered. A well-developed black vitrophyre occurs between the two Gallego flows and another at the base of the unit. The lower vitrophyre is exposed on a hill 2 km north of Rancho Aparejos. It is about 6 m thick and is less resistant than the overlying rhyolite. Black, perlitic vitrophyre with large phenocrysts of plagioclase, anorthoclase, and augite grades vertically into pinkish white, fine grained rock containing blocks of the black vitrophyre, 15 cm or less in diameter. Above this is a thin parting which is overlain by a mixture of red and black glass with red spherulites as large as 2 cm across. Three kilometers south of Rancho Coyamito a road cuts through black vitrophyre at the contact between the two flows. This may be a basal vitrophyre of the upper flow, the remainder of which has since been stripped away, or more plausibly it represents the chilled upper surface of the basal flow, as no erosional remnants of the upper flow are present and the vitrophyre is characteristically less resistant to weathering than the rest of the unit. This vitrophyre is virtually identical to the black vitrophyre at the base of the lower flow; it was sampled for chemical analysis, and phenocrysts from it were separated for K-Ar age determination.

In thin section the rock can be seen to be a lava flow, as it shows no shard or pumice structure, and in places is rich in large, unbroken phenocrysts. It varies from hypohyaline in the vitrophyre to holocrystalline in the middle of the flows. The groundmass is composed of alkali feldspar and quartz. Phenocrysts are dominantly large, euhedral oligoclase crystals as long as 9 mm that display oscillatory zoning and complex twinning. Twins include albite, pericline, and Carlsbad types. Many of the plagioclase grains have albite-twinned cores with untwinned rims, some of which are anorthoclase. The center portions of these grains are altered to sericite; the rims are unaltered. Phenocrysts of subhedral anorthoclase averaging 2 mm and exhibiting fine grid twinning and patchy zoning are also abundant. Fresh, anhedral augite phenocrysts, 1 mm or less in size, occur in the vitrophyre, but elsewhere they are altered to iron oxides and iddingsite (?). Subhedral zircons averaging .2 mm are disseminated throughout the rock, as are clear, .05 mm long needles of apatite (?).

Too much of the Gallego rhyolite lies outside the map area for a meaningful estimate of its total volume. Perhaps as much as 50 km^3 are exposed in the area investigated.

Mesteño Rhyolite

The Mesteño rhyolite is a widespread red, flow-layered rock that occurs prominently in at least two stratigraphic horizons, and makes up flows, flow domes, sills (?), and ash-flow tuffs (?). The lowest major layer of the Mesteño rhyolite unconformably overlies the Liebres formation; the second lies much higher in the stratigraphic sequence, directly above the Gallego rhyolite. The lower member averages 50 m and the upper one averages 65 m in thickness. The Mesteño rhyolite is the dominant volcanic rock in the eastern part of the map area, and fits the description of "red rhyolite flows and intrusions" that King and Adkins (1946) applied to bodies they mapped more than 50 km to the east. The outcrop pattern and topographic expression of the Mesteño rhyolite is variable. In the western portion of the map area, where thick units overlie both layers, it does not form conspicuous ridges; in many places in the east it forms pronounced ridges dipping gently westward. Elsewhere in the east, it commonly forms unlayered flow domes where it appears to have been highly viscous when extruded, piling up into mounds over vents instead of spreading laterally. The flow domes are of variable size; all are less than 2 km wide. Most of these flow domes are aligned along the eastern edge of the bolson in the central map area, and may represent lava squeezed up along the major faults on the eastern side of the graben which forms the bolson. If this is true, these flow domes occurred after or concurrently with the major faulting and, because both of the extensive layers of the Mesteño rhyolite are cut by major faulting, these flow domes may represent a separate phase of extrusion. Chapin and Seager (1975) contend that extensional faulting in New Mexico broke the roof of an Oligocene batholith and allowed the rise of igneous material. The emplacement of these flow domes could be the result of a similar mechanism. If the rhyolite did ascend along large faults, the age of these flow domes should give a minimum age for the major faulting in the area. Preliminary age determinations, however, indicate the flow domes are as old as the upper Mesteño rhyolite layer, apparently ruling out the possibility that they represent a later phase of extrusion related to Basin and Range faulting (Keller, personal communication). It is possible the flow dome rhyolite rose along zones of weakness that were later followed by major faulting.

In several places in northern Sierra Gallego, rhyolitic ash-flow tuff lies between the upper layer of the Mesteño rhyolite and overlying basalt flows. Because the basalt contains interbedded rhyolitic ash-flow tuff, the tuff directly above the Mesteño rhyolite was first mapped with the basalt. Preliminary K-Ar determinations on two samples of ash-flow tuff, however, indicate temporal proximity to the Mesteño rhyolite (Keller, personal communication). The Mesteño rhyolite therefore may locally have an ash-flow tuff counterpart.

The Mesteño rhyolite is generally moderate red (5R 4/6) on fresh surfaces and weathers grayish red (10R 4/2). The rock is crystal-poor and has flow-layering which gives it a characteristic "woody" appearance. The flow domes have especially contorted flow structure. The Mesteño rhyolite is in many places autobrecciated. The rock is strongly devitrified; in exposures at the southern end of Liebres, tiny spherulites have developed along the flow laminae, creating parting planes in the rock. The rock has the appearance of slate due to the resultant fissility.

Petrographically, the two rhyolite layers and the flow domes are indistinguishable, all highly devitrified to quartz and alkali feldspar from a formerly hypohyaline state. The groundmass exhibits granophyric recrystallization, and in places has anhedral quartz poikilitically enclosing laths of alkali feldspar. This micropoikilitic texture was first described by Reed in 1895. Anderson (1969) and Parker (1972) describing ash and lava flow rocks from West Texas have discussed this "snowflake texture" at length. Lufkin (1972) uses the term "sunflower" for the same texture in rhyolitic rocks of New Mexico. The texture is very common in devitrified silicic rocks. Lofgren (1971) has produced similar textures by experimental devitrification of natural rhyolite glass.

The few phenocrysts are feldspar, most of which are anorthoclase. Twinning in the phenocrysts includes fine grid twinning (albite and pericline), and Carlsbad. Patchy zoning is common. Long grains are in most places aligned parallel with flow. Small (.15 mm) zircons are concentrated around former mafic grains now altered to hematite. Hematite stains large areas of the rock around the opaque grains and is responsible for much of the red coloration of the rhyolite.

The upper layer of the Mesteño rhyolite is a lava flow. It is unclear at this time whether the lower layer is a flow or a sill. The data indicating it is a flow are:

1) numerous local occurrences of autobrecciation
2) the general lack of disturbance of overlying units
3) the lack of dikes of Mesteño rhyolite
4) the lack of sills of Mesteño rhyolite in other stratigraphic horizons
5) the apparent absence of overlying units under which it was injected if it is a sill. For example, north of Ejido Esperanza the Mesteño rhyolite occurs as a well-bedded, flat-topped ridge former in the bolson; small, black hills of Rancho El Agate tholeiitic andesite stratigraphically overlie the rhyolite, but appear to have been "stringers" or small accumulations of quickly chilled lava which flowed only over parts of the Mesteño rhyolite in this area, leaving most of it uncovered.
6) the rhyolite is rarely if ever absent between the Liebres and Rancho El Agate units.

The data indicating it is a sill are:

1) Similar "woody-textured" flow-layered rhyolite sills of Tertiary (?) age occur between Devonian and Silurian strata near Silver City, New Mexico.
2) Most convincing are K-Ar determinations (Keller, dissertation in progress) which indicate that a sample of Mesteño rhyolite collected from a mass of the unit in the bolson, stratigraphically overlying the Liebres formation, is younger than units overlying it. The sample was dated at 35.7±.6 m.y. old; the overlying Gallego rhyolite 37.1±.8 m.y. old.

If the K-Ar determinations are accurate, the lower member of the Mesteño must certainly be a sill.

Carneros Rhyolite

The Carneros rhyolite, which lies above the upper layer of the Mesteño rhyolite, was named from Sierra de los Carneros in the southwestern portion of the map area, where it forms both layered and massive peaks along that range's western margin. The steep peaks of massive rhyolite form a 4 km diameter ring around a broad, grassy flat area, producing a spectacular landscape. Besides the massive circular feature, the rock weathers spheroidally producing unusual shapes and perched rocks. The circular structure can be seen on a skylab photograph (Fig. 2) to merge to the north with a white streak which is a valley floored primarily with the rhyolite and a related underlying ashy agglomerate. Hills of layered rhyolite occur to the east of the circular feature, and three separate thick, ridge-forming flow units have been recognized. From the basal layer to the upper one, the units are respectively 26, 11, and 25 m in thickness. The layered rock contains scattered rock fragments of Gallego rhyolite and is slightly less indurated than the massive type, but is otherwise indistinguishable from it. Both are white, crystal-rich, two-feldspar rhyolites; the alkali feldspars are strongly chatoyant.

At the base of the three flows is a white agglomerate at least 50 m thick, which in mapping has been combined with the Carneros rhyolite. The agglomerate is composed of volcanic rock fragments and limestone cobbles in a friable grayish white grit and clay matrix. In the valley north of the circular feature, the agglomerate contains large boulders of flow-layered Mesteño rhyolite.

In thin section the Carneros rhyolite is composed 30-50 percent of slightly glomeroporphyritic phenocrysts of quartz, sanidine-anorthoclase, oligoclase, biotite, and magnetite in a fine groundmass of anhedral quartz and subhedral alkali feldspar microlites. Subequal amounts of quartz and sanidine-anorthoclase phenocrysts together make up about 30 percent of the rock. Both have crystals as large as 6 mm in diameter. The quartz crystals are anhedral and resorbed; some are embayed, but most merely show rounding. Surrounding most quartz phenocrysts are small particles of quartz in optical continuity with the larger grain. A few of these small particles are themselves embayed, indicating this is a resorption, not an overgrowth process.

This is not an isolated occurrence; the El Dos rhyolite, to be discussed below, exhibits identical quartz grains. Sanidine-anorthoclase phenocrysts are subhedral and have patchy and concentric zoning. Some grains have incomplete glassy cores. The alkali feldspar is microperthitic, and also cryptoperthitic as evidenced by the chatoyance of the grains. Oligoclase phenocrysts make up 10 percent of the rock and are as large as 2 mm; they are subhedral, complexly twinned and display strong oscillatory zoning. Biotite totals about one percent of the rock and is strongly altered to magnetite. Magnetite also occurs in euhedral crystals as large as 2 mm in diameter. Zircon is a common accessory mineral, averaging .05 mm in length.

The physiography and the massive nature of the rock of the circular structure indicates it is the remains of a large plug or flow dome which may have erupted in three major episodes producing the three flow units found to the east. Exposed faults radiate out from the intrusive area, suggesting that some doming has occurred.

El Dos Rhyolite (Agua Nueva Rhyolite)

A rhyolitic unit of unknown stratigraphic position is present in the southwestern portion of the map area. The unit was first named the El Dos rhyolite by Keller and myself but recently it has been renamed (by us) the Agua Nueva rhyolite. It forms another circular structure (see Skylab photo, Fig. 2), similar to but smaller than the Carneros rhyolite vent. The topography of this circular area is similar to the Carneros vent, with a broad, flat meadow ringed completely by massive hills of rhyolite. Northwest of the 2 km diameter feature is a bedded flow of the rhyolite. The base of the flow is not exposed and no units overlie it, indicating either that it is relatively young or that it was topographically high when other units were extruded. A chemical analysis indicates that the rock is silicified (83 percent SiO_2); therefore it cannot be compared with analyses of other rocks in the area. The rocks are everywhere closely jointed, except in the bedded flow; near the circular area jointing has cut the rock to such a degree that pieces larger than 3 cm in diameter cannot be found.

In thin section the rock is porphyritic with phenocrysts of quartz, anorthoclase, and plagioclase, some of which have anorthoclase rims. Biotite as large as 2.5 mm wide occurs poikilitically enclosing groundmass quartz and feldspar. Quartz pehnocrysts averaging 2 mm across are surrounded by small particles of quartz in optical continuity, identical to those found in the Carneros rhyolite. One large (1 cm) quartz crystal poikilitically encloses several 2 mm alkali feldspar phenocrysts. Anorthoclase phenocrysts as great as 5 mm are anhedral, having irregular, and in places poikilitic, borders. Albite twinned plagioclase grains, strongly altered to sericite, in many samples have unaltered anorthoclase rims. The quartz resorption and anorthoclase rimming may indicate an enrichment in potassium, sodium and aluminum (?) in the melt which compositionally favored formation of anorthoclase and biotite at the expense of quartz.

The El Dos rhyolite is similar to the Carneros but is finer grained and contains fewer alkali feldspar phenocrysts. No chatoyance is present in the alkali feldspars from the

El Dos rhyolite. The El Dos circular structure lies 10 km from the Carneros plug and is similar in all respects to it. It is therefore also considered to be a plug. A radiating fault pattern similar to that of the Carneros is suggestive of doming. The bedded El Dos rhyolite probably was erupted from this vent. Because of its proximity and similarity to exposures of the Carneros rhyolite, and its generally similar mineralogy, I consider the El Dos rhyolite to be essentially the same age as the Carneros rhyolite. K-Ar determinations support this contention; the El Dos rhyolite is 35.2±.8 m.y. old and the Carneros rhyolite is 35.1±.8 m.y. old.

Rancho El Milagro Basalt

The Rancho El Milagro basalt stratigraphically overlies the Carneros rhyolite and all other volcanic units in the map area, with the possible exception of the Mesteño flow domes. The unit is composed of at least 25 individual flows averaging 5 m in thickness. The flows are slightly thicker near the base of the unit and progressively thinner upward. Occurrences of the basalt are limited to the western half of the study area. A section measured about 4 km northwest of Rancho El Milagro recorded a thickness of 140 m, but the top was erosional. The basalt is grayish black (N-2) and generally vesicular. Amygdules of calcite are common. A rhyolite ashflow tuff is interbedded near the top of the unit in the section measured northwest of Rancho El Milagro. The ash flow is also present in the basalt near Alamo on Coyamito road. The ash-flow tuff is slightly less than 10 m thick and has a well-developed basal vitrophyre. The tuff has a wide range of color (from yellow to black) depending on the degree of welding.

In thin section the basalt contains variable phenocryst assemblages. Some thin sections feature large, greater than 2.5 mm in diameter, subhedral, skeletal olivine crystals in a mass of trachytoid plagioclase microlites, groundmass olivine, and black glass. All thin sections contain olivine; in most the olivine is partially or wholly altered to iddingsite. Most slides contain some clinopyroxene and in some it is the most abundant phenocryst. Three km west of Rancho Agua Nueva (Plate 1) the basalt contains 1 mm long, euhedral augite crystals which are twinned, slightly zoned, and have incomplete cores. The cores of these grains contain glass and plagioclase.

In thin section the ash-flow tuff exhibits very fresh, strongly contorted shards (Fig. 7). Phenocrysts include euhedral augite as large as 1 mm in diameter, biotite as large as 1 mm, partially altered to opaque minerals, and .5 mm long, euhedral sphene.

The occurrence of interlayered basaltic and rhyolitic rocks without compositionally intermediate rocks is bimodal

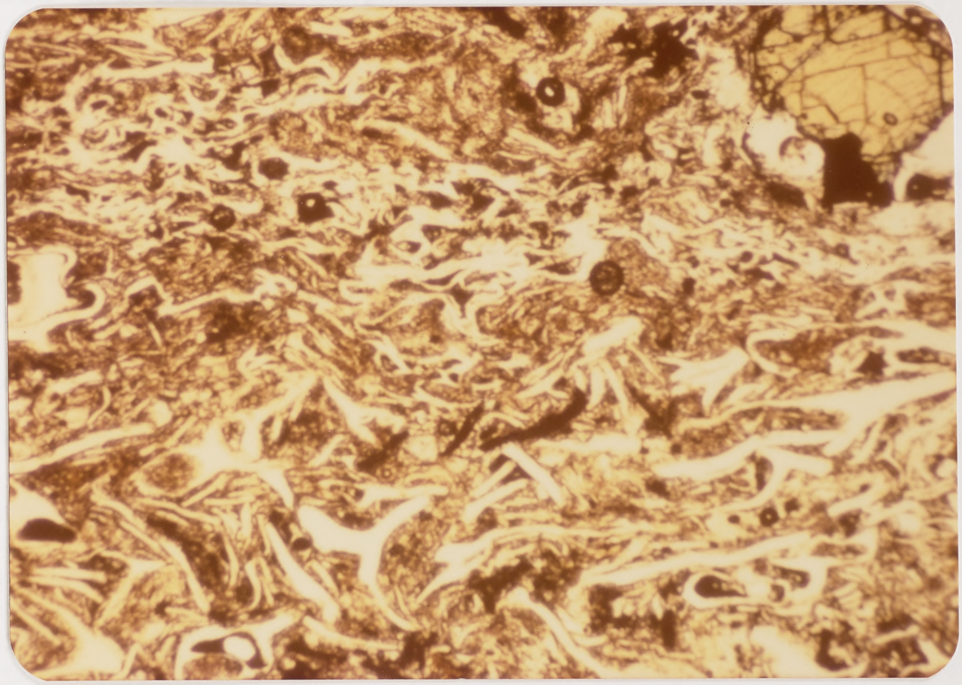


Figure 7. Photomicrograph (plane light) of the ash-flow tuff of the bimodal Milagro basalt. Moderately to strongly contorted shards of varying thicknesses. Yellow-green crystal at upper right is augite. Long dimension is 2.2 mm.

volcanism, sometimes called the Daly gap, and is common in the geologic record. Many authors, including Lipman and others (1972), and Chapin and Seager (1975) contend that bimodal volcanism is commonly related to Basin and Range extensional faulting. Christensen and Lipman (1972) suggest that ash-flow tuffs are related to partial melting by the upward rise of basaltic magma. Mauger (1975), citing the paucity of basalt-related rhyolitic ash-flows in the Majalca area, 50 km south of the map area, contends that the Christiansen and Lipman theory of ash-flow tuff petrogenesis is not valid in Chihuahua. The rocks in the El Sueco area tend to suggest the opposite.

The source of the basalt in the map area is unknown; the abundance of the rock toward the west suggests a source area in that direction. A small cone approximately 1 km in diameter is located 10 km west of El Sueco, and may have supplied some material. It is probable there were several sources. On enlarged skylab photos relatively undissected piles of what appear to be basalt occur at the northeastern base of Sierra del Nido. These little-eroded features indicate either that the mafic volcanism is all relatively young, or that it occurred over an extended period of time, having recently ceased. The K-Ar age determination for the basalt of more than 28 m.y. suggests the latter.

The basalt covers at least 400 km^2 of the map area. A conservative estimate of its average thickness is 125 m. The volume of Rancho El Milagro basalt in the map area is therefore at least 50 km^3.

Conglomerate Units

Two conglomerate units are found overlying the volcanic section in the area; one well-indurated multi-rock type conglomerate, the other a less consolidated basalt conglomerate.

The multi-rock type conglomerate is limited to a small area about 10 km south of Ejido Esperanza. The total outcrop of the unit is less than three km^2. The unit is moderately well bedded, and exhibits numerous graded bedding intervals each averaging one meter in thickness. The beds dip to the north about 12 degrees. The matrix is poorly sorted, well indurated, siliceous, and dark red-brown, giving the entire unit a red hue that can be seen on a skylab photo (Fig. 2). The conglomerate contains subrounded boulders, cobbles and pebbles of Rancho El Agate tholeiitic andesite, Mesteño, Gallego, and Carneros rhyolite, and Milagro basalt.

The thickness of the unit is unknown but is on the order of 60 m. No fossils were seen. The ruin of an Indian dwelling is present in a small cave in the unit.

The conglomerate is younger than the Milagro basalt as it includes cobbles of that rock as a framework constituent.

The unit is believed to represent material shed off a large fault scarp which experienced many small uplifts, producing the numerous graded beds. The unit was lithified and was itself faulted to its present position.

The basalt conglomerate is restricted to the southwestern portion of the map area. It covers an area of approximately 20 km^2, and occurs in places as a thin veneer over the Milagro basalt. Elsewhere, in stream channels it can be seen to be at least 10 m thick. The matrix is a mixture of clay and caliche. Boulders of the basalt as great as 50 cm are present. To the west and north it is covered by bolson fill. It was formed as a result of the faulting which has tilted the Milagro basalt to the west.

Bolson Deposits

Bolson deposits cover approximately two-fifths of the map area and were not studied in detail. The major bolson deposits are on either side of the north-trending Sierra Gallego. The few streams in the area have not cut down sufficiently to produce good exposures. On the surface and in the small stream cuts the bolson fill is generally non-indurated, pale brown, poorly sorted gravel to clay. All unconsolidated fill material was mapped as Quaternary alluvium. Both alluvial and colluvial processes appear to have contributed significant amounts of material. The composition and relative abundance of clasts is strongly controlled by the type of rocks that crop out in adjacent ranges.

The maximum thickness of bolson fill is unknown. Dickerson (1966) reported that well data indicate a thickness of at least 925 m in the Presidio Bolson, 100 km east of the map area. Geophysical work could be done to determine the thickness of the bolson and the amount of displacement of the large faults forming the graben in which the bolson occurs.

CORRELATION

Several tentative correlations may be made between rock units in the map area and those in surrounding regions. The limestone conglomerate at the base of the Liebres formation is comparable to the Jeff Conglomerate to the east (Eifler, 1951; McKnight, 1968) and the conglomerate of the Pozos Formation to the south (Alba and Chavez, 1974). The Jeff Conglomerate extends over much of the Big Bend region of West Texas. Pebbles of quartzite are found in the conglomerate of the map area, and also in the Buck Hill quadrangle (Goldich and Elms, 1949) and Barrilla Mountains (Eifler, 1951), but McKnight (1968) found no quartzite in the Bofecillos area. McKnight contended that the gravel was left on an erosion surface as a residuum that surrounded local topographic highlands where it was not deposited. He recognized a probable highland west of the Bofecillos Mountains on which the conglomerate was not deposited. This highland would have lain between the Bofecillos Mountains and the Sierra Gallego area and probably was related to Laramide deformation and uplift.

Alba and Chavez (1974, Fig. 1) picture the Pozos Formation in a geologic column at Sierra Peña Blanca as an Eocene limestone and volcanic rock conglomerate resting on the Lower

Cretaceous Edwards Formation and overlain by felsic flows and ash-flow tuffs ranging in age from approximately 37 to 44 m.y. No further description of the unit is given in the article.

It is evident that many large deposits of gravel accumulated locally over a vast post-Laramide erosional surface covering much of West Texas and Chihuahua. Although the gravel may not be everywhere isochronous, there is probably a large general overlap of ages of these conglomeratic deposits.

The Instituto Nacional de Energía Nuclear is developing a uranium mine approximately 45 km south of the map area. Their stratigraphic section includes a series of tuff and rhyolite above the Pozos Formation. During a short trip to the mine area, we did not recognize any of the volcanic rocks as being the same as those in our area; nevertheless, the general sequence of a thick series of rhyolitic tuff resting on the basal limestone-conglomerate and overlain by intermediate rocks is closely similar to our first and second volcanic sequences. It is significant that the Sierra Gallego map area has counterparts far to the south, and that volcanism in the region began with many widely-spaced, partly overlapping, rhyolitic ash-flow tuffs, followed by lavas of intermediate composition.

Lastly, the Mesteño rhyolite is tentatively correlated with the unnamed and undescribed "red rhyolite flows and intrusions" 50 km to the east mentioned by King and Adkins (1946).

Air photo study indicates flow domes of the Mesteño rhyolite are the only volcanic rocks of the map area which continue to the east.

STRUCTURE

Regional Structure

The map area lies in the Basin and Range physiographic province, a region marked by large Cenozoic normal faults trending north-northwest. This fault pattern is superimposed over Laramide faulting and folding which deformed Cretaceous and older rocks in the Chihuahua Trough and to a lesser extent those on the Aldama Platform (see Fig. 16).

The area also lies on a southward projection of the trend of the Rio Grande rift. In recent years there has been much controversy about this rift zone, a large, north-trending structural depression, especially concerning its nature in southern New Mexico and northern Chihuahua. Chapin (1971a) and other authors (Woodward, Callender, and Zilinski, 1975; Kelley, 1952; and Sanford, 1968) have traced the Rio Grande rift for 1000 km from the Southern Rocky Mountains physiographic province of Central Colorado into the Mexican Basin and Range province of northern Chihuahua. The rift zone widens from 100 km or less in Colorado to greater than 250 km in northern Chihuahua and Texas (Chapin and Seager, 1975). Sanford (1968), noting the more subdued topography and smaller gravity anomalies along the rift zone south of Albuquerque, concluded the zone merges with the Basin and Range province. Chapin and Seager (1975, Fig. 2) leave their tracing of the southern end of the zone in northern Chihuahua open with a question mark, indicating that a continuation of the rift as a through-going structure has not been ruled out.

Eardley (1951) recognized that the Colorado Plateau appears to have moved away from the eastern United States while at the same time rotating clockwise producing the Rio Grande Rift. If this actually happened, it would explain the widening of the zone to the south. Muehlberger (1976, personal communication) has stated that the delineation of the zone in southern New Mexico is arbitrary, as the Basin and Range faulting is of the same age as Rio Grande rifting. If there is in fact a through-going Mexican Rio Grande rift structure distinct from Basin and Range faulting, it may follow the trend of either the Chihuahua Trough or the "Texas Lineament" as Chapin and Seager (1975) have shown it to closely follow older structural zones. Future detailed geophysical studies will probably end this controversy.

Local Structure

Large normal faults border the great majority of the ranges in the area. Many of these faults are several tens of kilometers long.

The throw on these faults is at least equal to, and probably much greater than, the relief of the ranges which at Sierra Gallego is more than 1200 m.

All faulting in the volcanic rocks of the area appears to be of the high angle normal type. Most faults strike north-northwest, but a few smaller ones strike north and northeast. Some of the faults have arcuate patterns. Intrusions of Carneros, El Dos and Mesteño rhyolite have doming and related faulting in the southwestern portion of the map area. The doming is recognized both by the attitudes of surrounding layers and from the radiating fault pattern.

The carbonate ranges forming the eastern border of the map area exhibit intense folding, thrust faulting and high-angle normal faulting. General trends of ranges of carbonate and of volcanic rocks are similar, but the great majority of volcanic layers in the ranges and hills of the map area dip at a low angle to the west, whereas the beds in the carbonate ranges dip to the east. The volcanic rocks have experienced only the faulting, which has tended to tilt strata to the west. This faulting also strongly affected the carbonate rocks, but these rocks had already been involved in Laramide deformation. Much of the Laramide deformation was caused by uplift of the Aldama Platform and resultant eastward tilting and sliding of beds on an evaporitic base (DeFord, 1969).

PETROLOGY

Chemistry

Introduction

Fifteen chemical analyses of rocks from the area are provided in Table 2. A tuff from the Liebres formation and the El Dos rhyolite proved to be too leached and altered for satisfactory analysis. They have been included in Table 2 for completeness but are not considered further. There are numerous problems inherent in obtaining reliable chemical data on volcanic and pyroclastic rocks; among them are the following:

1) Volatiles are extensively lost during eruption and emplacement of ash-flow tuffs.
2) The loss of alkalies during crystallization and devitrification has been demonstrated by numerous authors (Lipman, 1965; Lofgren, 1970; Scott, 1966 and 1971b; Macdonald and Bailey, 1973).
3) Alkalies and silicon can be leached by groundwater.
4) Groundwater can add calcium, magnesium, and silicon, and will greatly speed oxidation of iron and hydration of minerals (Scott, 1966 and 1971b; Aramaki and Lipman, 1965; Lipman, 1965; and Noble, 1967).
5) Rock fragments can add spurious components.
6) Inhomogeneities in magma chambers can cause variable concentrations of phenocrysts in ash-flow sheets erupted from them (Smith and Bailey, 1966; and Lipman and others, 1966).

Lipman (1967), and Sheridan (1976, personal communication) have concluded that ash-flow compositions are best exemplified by

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	LIEBRES TUFF	RANCHO EL AGATE	RANCHO EL AGATE	GALLEGO FLOW	MESTENO RHYOLITE FLOW	MESTENO RHYOLITE TUFF	MESTENO RHYOLITE TUFF	CARNEROS RHYOLITE PLUG	CARNEROS RHYOLITE FLOW	AGUA NUEVA RHYOLITE	MILAGRO BASALT	MILAGRO BASALT	MILAGRO BASALT	MILAGRO BASALT	MILAGRO BASALT
SiO_2	82.24	59.36	59.36	68.34	71.51	70.48	75.90	74.26	72.88	77.49	52.89	54.96	56.37	54.07	54.18
TiO_2	0.15	1.43	1.45	0.15	0.47	0.29	0.31	0.33	0.40	0.15	1.90	1.55	1.57	1.83	1.86
Al_2O_3	9.20	15.60	15.10	14.19	13.64	12.22	12.32	13.59	14.09	12.65	15.87	15.40	15.61	15.92	16.03
Fe_2O_3	0.85	6.25	2.93	1.36	3.03	1.53	1.26	2.15	2.67	1.08	3.79	6.23	3.48	4.32	8.55
FeO	0.05	1.04	3.98	1.39	0.09	0.23	0.14	0.22	0.05	0.08	5.94	1.82	4.07	4.86	0.75
MnO	0.01	0.09	0.14	0.05	0.01	0.10	0.05	0.07	0.08	0.00	0.13	0.10	0.13	0.13	0.15
MgO	0.04	2.18	2.43	0.27	0.16	0.60	0.14	0.21	0.41	0.07	4.60	4.06	4.30	4.02	3.20
CaO	0.29	4.40	4.59	1.23	0.47	0.47	0.39	0.77	1.13	0.08	7.58	6.70	7.11	6.92	6.78
Na_2O	1.89	4.13	3.97	3.61	3.83	2.51	3.91	3.54	3.68	3.31	3.52	3.69	3.73	3.69	4.02
K_2O	5.53	3.48	3.32	5.50	5.27	5.57	4.75	4.42	4.61	4.44	1.52	1.93	2.18	2.29	2.65
H_2O^+	0.05	0.72	1.27	2.58	0.57	3.80	0.35	0.11	0.10	0.44	0.66	1.13	0.53	0.38	0.43
H_2O^-	0.10	0.88	0.35	0.26	0.43	1.40	0.27	0.17	0.08	0.48	0.20	1.03	0.23	0.14	0.35
P_2O_5	0.05	0.48	0.58	0.10	0.17	0.03	0.06	0.10	0.13	0.02	0.61	0.71	0.66	0.81	0.84
CO_2	0.03	0.02	0.11	0.01	0.01	0.00	0.10	0.00	0.00	0.00	0.41	0.02	0.09	0.25	0.01
TOTAL	99.88	99.86	99.58	99.50	99.68	99.39	99.95	99.94	100.31	100.29	99.62	99.33	100.08	99.63	99.90
q	49.72	11.88	11.80	23.11	26.18	32.64	34.10	35.07	31.17	41.03	5.85	9.20	8.17	6.40	5.95
or	32.67	20.56	19.62	32.50	31.14	32.91	28.06	26.12	27.24	26.23	8.98	11.40	12.88	13.53	15.66
ab	15.99	34.95	33.59	30.55	32.58	21.24	33.09	29.96	31.14	28.01	29.79	31.22	31.56	31.22	34.02
an	0.29	13.21	13.58	5.39	1.22	2.14	1.54	3.17	4.76	0.27	23.02	19.76	19.41	20.12	17.87
di	0.21	3.80	3.80	-	-	-	-	-	-	-	6.46	6.85	8.61	5.85	5.68
hy	-	3.67	6.97	1.60	0.40	1.73	0.35	0.52	1.02	0.17	13.22	7.87	8.87	9.80	5.34
il	0.13	2.39	2.75	0.97	0.21	0.55	0.40	0.61	0.28	0.17	3.61	2.94	2.98	3.48	1.90
ap	0.12	1.14	1.37	0.24	0.40	0.07	0.14	0.24	0.31	0.05	1.44	1.68	1.61	1.92	1.99
c	-	-	-	0.33	1.16	1.28	0.10	1.82	1.30	2.30	-	-	-	-	-
cc	-	-	-	0.02	-	-	-	-	-	-	0.93	0.05	0.20	0.57	-
ru	-	-	-	-	0.36	-	0.10	0.01	0.25	0.06	-	-	-	-	-
mt	-	-	-	1.97	-	0.42	-	-	-	-	5.50	1.70	5.05	6.26	-
tn	0.20	0.42	-	-	-	-	-	-	-	-	-	-	-	-	2.10
hm	0.85	6.25	-	-	3.03	1.34	1.26	2.15	2.67	1.08	-	5.06	-	-	8.05
TOTAL Norm.	100.30	98.26	97.99	96.66	98.68	94.32	99.23	99.66	100.14	99.37	98.79	97.73	99.36	99.15	99.15
Plag.(An)	1.79	27.43	28.79	14.99	3.61	9.14	4.46	9.56	13.25	0.94	43.59	38.76	38.08	39.18	34.44
D I	98.39	67.39	65.01	88.15	91.90	86.79	95.26	91.14	89.54	95.27	44.61	51.83	52.61	51.16	55.62
(Na+K)/Al(mol)	.988	.686	.670	.838	.882	.831	.939	.780	.754	.810	.469	.530	.544	.537	.591

Analyses performed by Karl Hoops and Peter Keller, Department of Geological Sciences, The University of Texas - Austin.

Table 2. Original chemical analyses and norms.

the interior portions of large, non-hydrated, glassy pumice boulders, but because these are rare, Lipman (1965), and Lipman and others (1969) contend that glass devitrified during cooling represents the best possible alternative. All of the samples of ash-flow tuffs for chemical analysis were collected from devitrified zones.

Classification

The rocks have been classified by norms according to the system of Irvine and Baragar (1971). The results obtained from this classification have been modified using the system of Streckeisen (1976), the Peacock alkali-lime index (Peacock, 1931), and Shand's aluminum saturation method (Shand, 1951). The chemical data have been recalculated volatile-free to 100 percent and were corrected for oxidation. An upper limit on Fe_2O_3 was set by the following equation: % Fe_2O_3 = % TiO_2 + 1.5, (as specified by Irvine and Baragar, 1971). When an analysis value of Fe_2O_3 was less than its TiO_2 plus 1.5, no change was made; when it was higher the "excess" Fe_2O_3 was converted to FeO. For the recalculated data and norms the reader is referred to Keller (dissertation in progress).

The norm results are expressed in weight percent as in classical CIPW procedure, rather than in percent cation equivalents which are preferred for the Irvine and Baragar classification. The results obtained from the two systems are generally similar except that the ore mineral values are only about two-thirds as large in the cation equivalents norms (Irvine and Baragar, 1971).

According to the system of Irvine and Baragar, all rocks were first categorized as subalkaline or alkaline depending on their plot on three diagrams. The first and simplest (Fig. 8a) is a weight percent plot of Na_2O & K_2O against SiO_2 in which all the rocks but one, the neck within the basalt cone west of El Sueco, fall in the subalkaline field. The basalt cone and the Rancho El Agate samples fall on or very close to the dividing line proposed by Irvine and Baragar (1971), whereas MacDonald's (1968) line of division would classify them as alkaline (Fig. 8a).

The other two diagrams, the Ne-Ol-Q triangle (Fig. 8b), and the Ol-Cpx-Opx diagram (Fig. 8c) indicate all the rocks to be subalkaline. Because Irvine and Baragar (1971) contend that the Ne-Ol-Q triangle is the best of the three for general purposes, and the Ol-Cpx-Opx triangle is probably best for basalt classification, the basalt that plotted as alkaline in Figure 8a will be considered subalkaline with the rest. Further substantiation of the subalkalinity of the El Sueco volcanic suite comes from the fact that all the samples are quartz and hypersthene normative; therefore all are silica-oversaturated and none is alkaline.

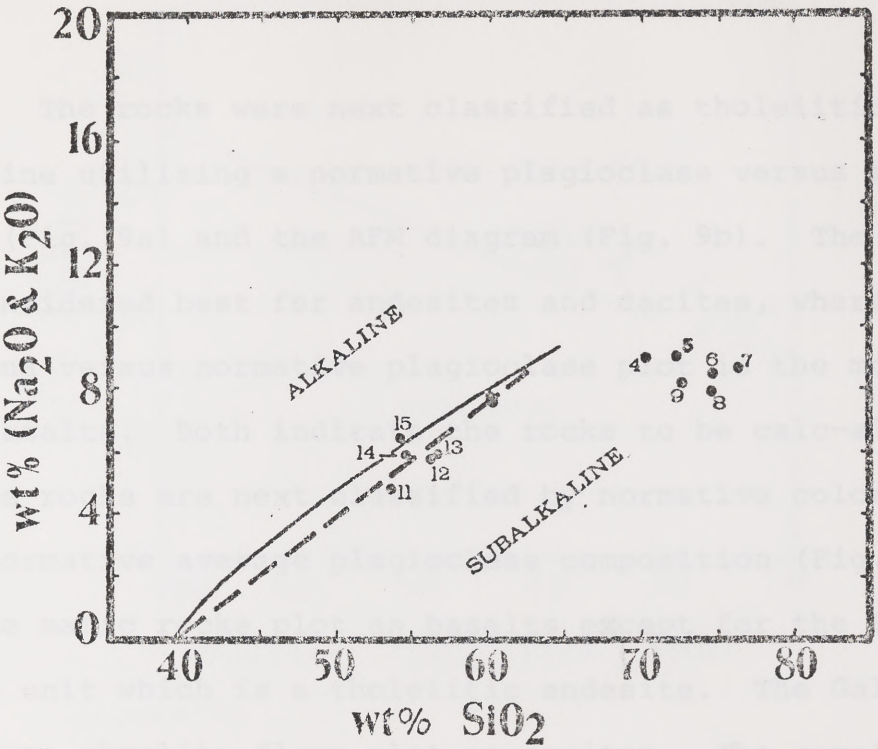


Figure 8a

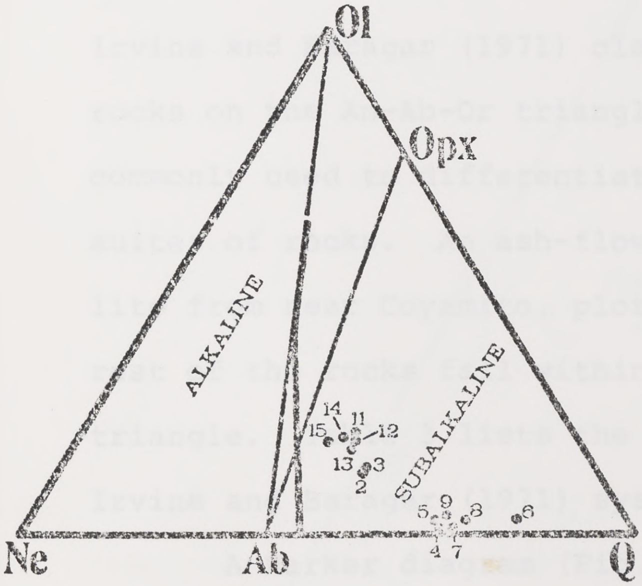


Figure 8b

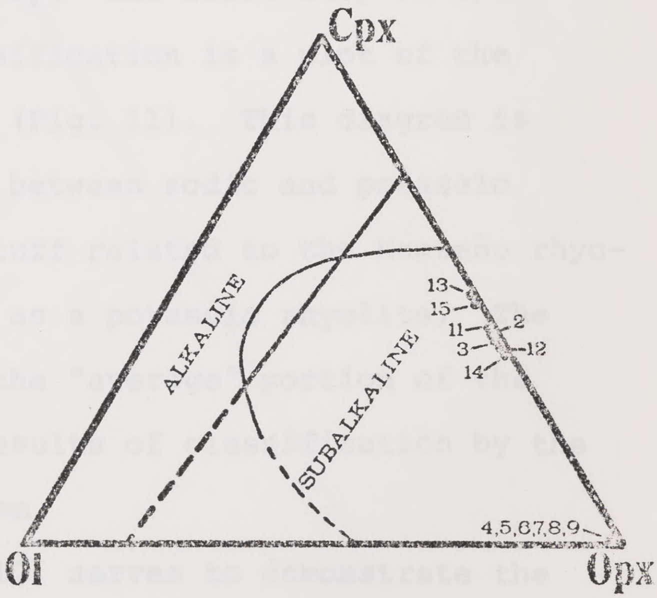


Figure 8c

Figure 8. Diagrams for use in alkalinity classification from Irvine and Baragar (1971). In Figure 8a, dashed line is divider proposed by MacDonald (1968). Curved line is divider proposed by Irvine and Baragar (1971). Numbers refer to list of rocks in Table 2.

The rocks were next classified as tholeiitic or calc-alkaline utilizing a normative plagioclase versus alumina diagram (Fig. 9a) and the AFM diagram (Fig. 9b). The AFM diagram is considered best for andesites and dacites, whereas the alumina versus normative plagioclase plot is the more reliable for basalts. Both indicate the rocks to be calc-alkaline. All of the rocks are next classified by normative color index versus normative average plagioclase composition (Fig. 10). All of the mafic rocks plot as basalts except for the Rancho El Agate unit which is a tholeiitic andesite. The Gallego and Carneros rhyolite flows plot as dacites. The remaining rocks all fall in the rhyolite category. The final step in the Irvine and Baragar (1971) classification is a plot of the rocks on the An-Ab-Or triangle (Fig. 11). This diagram is commonly used to differentiate between sodic and potassic suites of rocks. An ash-flow tuff related to the Mesteño rhyolite from near Coyamito, plots as a potassic rhyolite. The rest of the rocks fall within the "average" portion of the triangle. Table 3 lists the results of classification by the Irvine and Baragar (1971) system.

A Harker diagram (Fig. 12) serves to demonstrate the bimodality of the El Sueco volcanic suite with respect to silica. The Peacock index is easily derived from the diagram by interpolating the SiO_2 value at which the "smoothed" CaO curve intersects the "smoothed" (Na_2O & K_2O) curve. If the

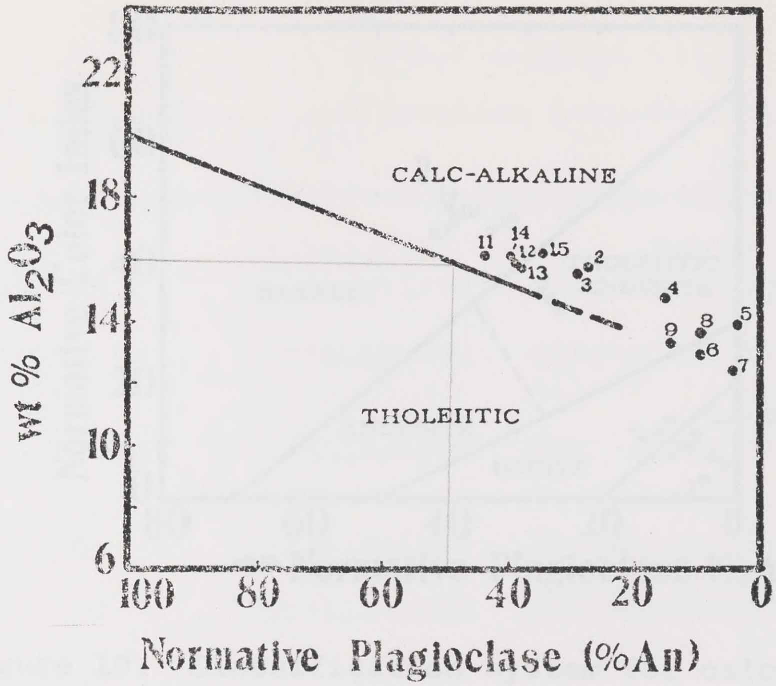


Figure 9a

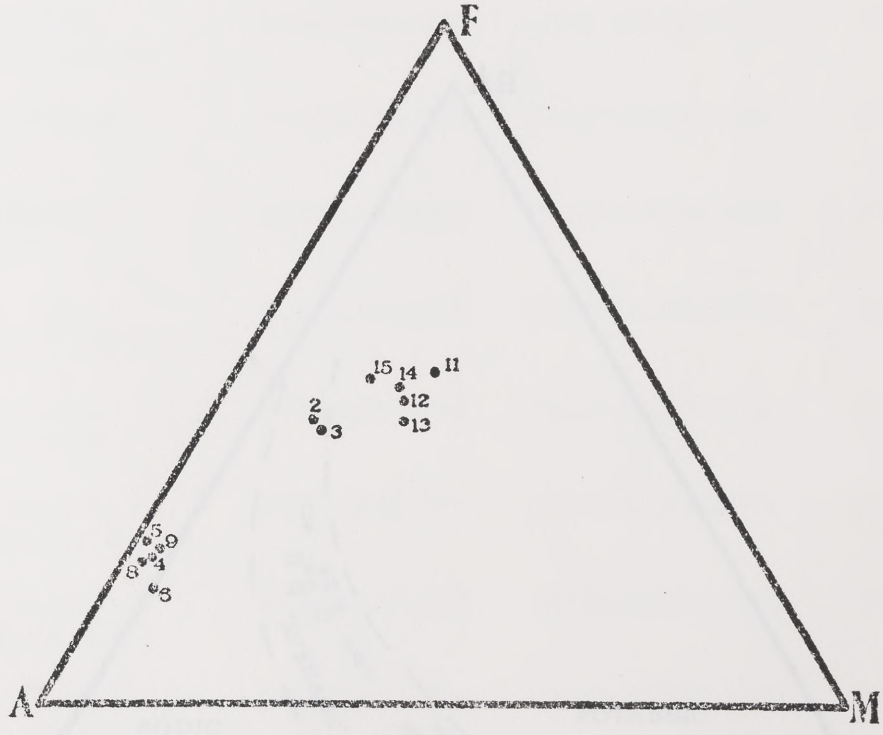


Figure 9b

Figure 9a & b. Diagrams for calc-alkaline vs. tholeiitic classification. (From Irvine and Baragar (1971)).

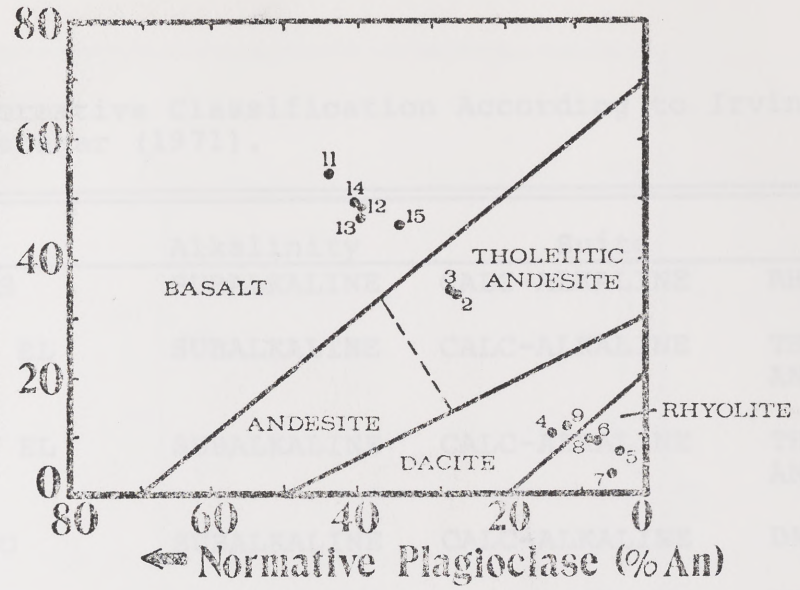


Figure 10. Classification system for calc-alkaline rocks. From Irvine & Baragar (1971).

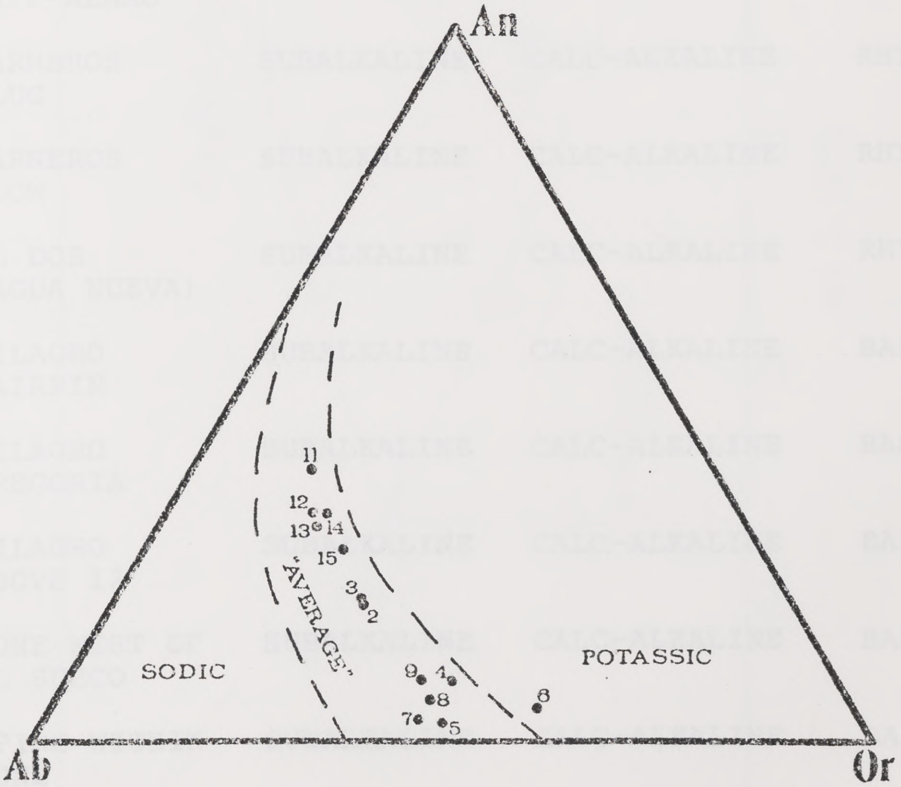


Figure 11. Triangle differentiating sodic versus potassic suites of rocks. From Irvine and Baragar (1971).

Table 3. Normative Classification According to Irvine and Baragar (1971).

No.	Unit	Alkalinity	Suite	Name
1	LIEBRES	SUBALKALINE	CALC-ALKALINE	RHYOLITE
2	RANCHO EL AGATE	SUBALKALINE	CALC-ALKALINE	THOLEIITIC ANDESITE
3	RANCHO EL AGATE	SUBALKALINE	CALC-ALKALINE	THOLEIITIC ANDESITE
4	GALLEGO	SUBALKALINE	CALC-ALKALINE	DACITE
5	MESTEÑO	SUBALKALINE	CALC-ALKALINE	RHYOLITE
6	MESTEÑO TUFF-COYAMITO	SUBALKALINE	CALC-ALKALINE	POTASSIC RHYOLITE
7	MESTEÑO TUFF-ALAMO	SUBALKALINE	CALC-ALKALINE	RHYOLITE
8	CARNEROS PLUG	SUBALKALINE	CALC-ALKALINE	RHYOLITE
9	CARNEROS FLOW	SUBALKALINE	CALC-ALKALINE	RHYOLITE
10	EL DOS (AGUA NUEVA)	SUBALKALINE	CALC-ALKALINE	RHYOLITE
11	MILAGRO HAIRPIN	SUBALKALINE	CALC-ALKALINE	BASALT
12	MILAGRO GREGORIA	SUBALKALINE	CALC-ALKALINE	BASALT
13	MILAGRO ABOVE 12	SUBALKALINE	CALC-ALKALINE	BASALT
14	CONE WEST OF EL SUECO	SUBALKALINE	CALC-ALKALINE	BASALT
15	SPINE WITHIN CONE	SUBALKALINE	CALC-ALKALINE	BASALT

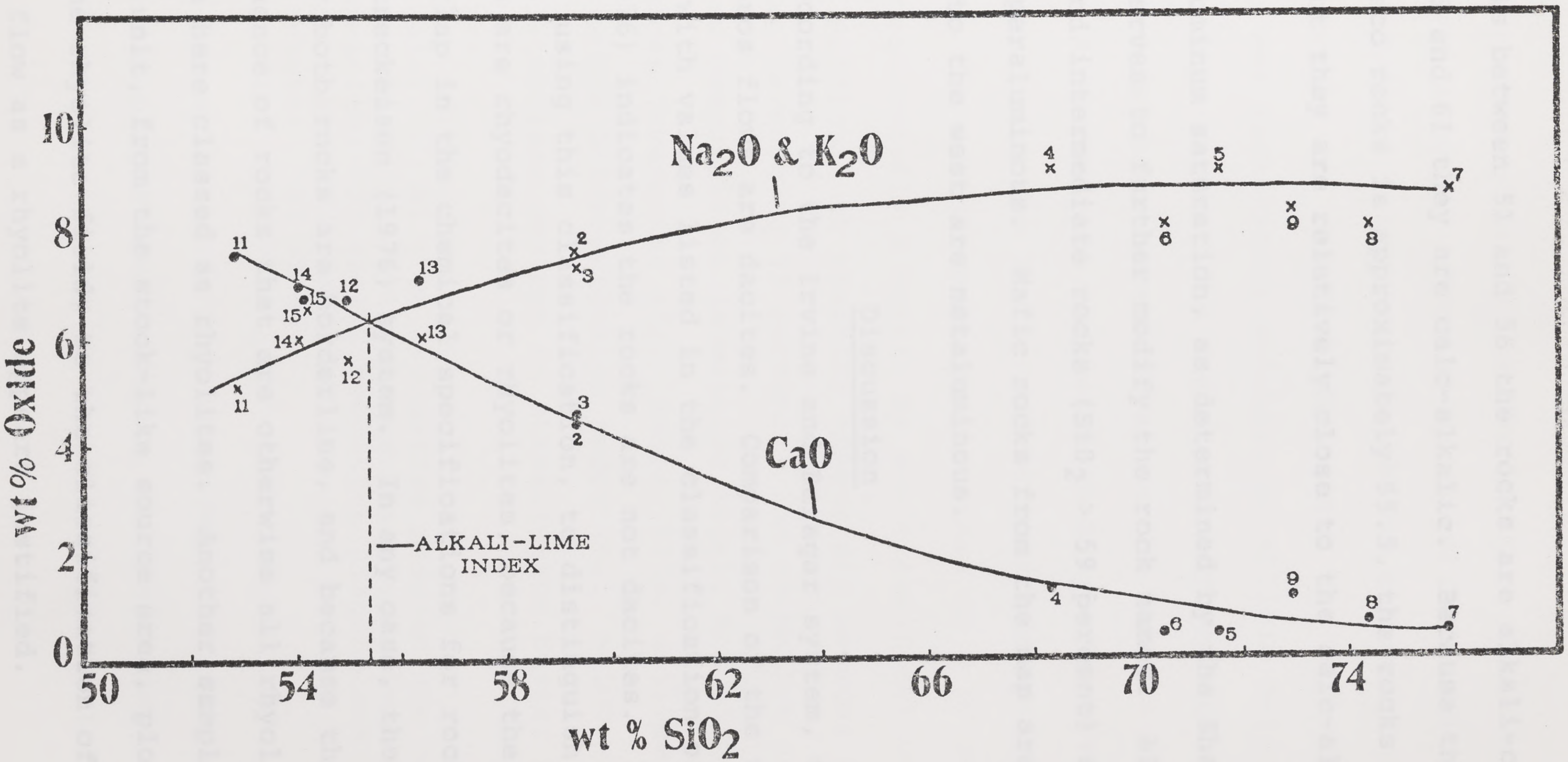


Figure 12. Harker diagram illustrating bimodality of El Sueco volcanic suite with respect to silica. Peacock Index is between 55 and 56. The rocks are therefore alkali calcic.

value falls between 51 and 56 the rocks are alkali-calcic; if between 56 and 61 they are calc-alkalic. Because the value for the El Sueco rocks is approximately 55.5, the rocks are alkali-calcic, but they are relatively close to the calc-alkalic index.

Aluminum saturation, as determined by the Shand (1951) system, serves to further modify the rock names. All analyzed silicic and intermediate rocks (SiO_2 > 59 percent) from the map area are peraluminous. Mafic rocks from the map area and from the cone to the west are metaluminous.

Discussion

According to the Irvine and Baragar system, the Gallego and Carneros flows are dacites. Comparison of the units' chemical data with values listed in the classification of Streckeisen (1976) indicates the rocks are not dacites. It is impossible, using this classification, to distinguish whether the rocks are rhyodacites or rhyolites, because there is too much overlap in the chemical specifications for rock groups in the Streckeisen (1976) system. In any case, the distinctions for both rocks are borderline, and because they occur in a sequence of rocks that are otherwise all rhyolites, both flows are here classed as rhyolites. Another sample of the Carneros unit, from the stock-like source area, plotted well within the rhyolite field, so the classification of the Carneros flow as a rhyolite appears justified.

The chemistry of the Rancho El Agate tholeiitic andesite may have been strongly affected by assimilation of silicic rocks or lavas. Fritted feldspars, thought to represent partially fused xenocrysts are abundant throughout the rock. These indicate there was significant addition of silicic material to the Rancho El Agate magma. The magma probably was originally basaltic and may have been similar to the Milagro basalt.

The five analyzed samples with $SiO_2 < 59$ percent all plot as basalts in the Irvine and Baragar system. In all of these rocks the normative plagioclase has An < 50 percent, so none is unequivocally a basalt by all classifications. The rocks are difficult to classify adequately because they have high silica (averaging 55 percent), low normative average plagioclase compositions (averaging An_{39}), and high normative color indices (averaging 47). Baker (1974) utilizes the Thornton-Tuttle Differentiation Index (D.I. = 100 - C.I.) and average plagioclase content to classify the Easter Island volcanic suite:

basalt:	DI < 30, normative plagioclase $>An_{50}$
hawaiite:	DI 30-45, normative plagioclase An_{50}-An_{30}
mugearite:	DI 45-65, normative plagioclase $<An_{30}$
benmoreite:	DI 65-75
trachyte:	DI 75-90
rhyolite:	DI > 90

Where the two criteria do not coincide, priority is given to the normative plagioclase content. By these standards, our mafic rocks are equivalent to hawaiites and the intermediate

Rancho El Agate unit to mugearite. Both the intermediate and mafic rocks have differentiation indices too large for exact fits. Irvine and Baragar (1971) include a classification diagram for the hawaiite-mugearite-benmoreite-trachyte-rhyolite suite, but it is used only if the rocks are alkaline, and according to figures X, Y, and Z ours are not. There remains some question about the alkalinity, however, and a plot sloping down to the left indicating they are alkaline rather than calc-alkaline. The degree of slope is indicative of the degree of alkalinity and the silicic rocks have very low slopes suggesting they are intermediate between calc-alkaline and alkaline; the mafic rocks have high slopes indicating they are strongly alkaline. This is in contrast to the results derived from the Shand (1951) classification.

Comparisons of Analyses from the Sierra Madre Occidental, El Sueco, West Texas, and Related Areas

Much interest has focused on the study area because it is geographically centered between the Sierra Madre Occidental calc-alkaline province and the Trans-Pecos Texas alkaline province. Swanson (1974) and Swanson and others (in press) have noted that rhyolitic rocks of the Sierra Madre Occidental from Mazatlán to Durango become enriched in silicon and potassium and depleted in sodium, calcium and aluminum eastward.

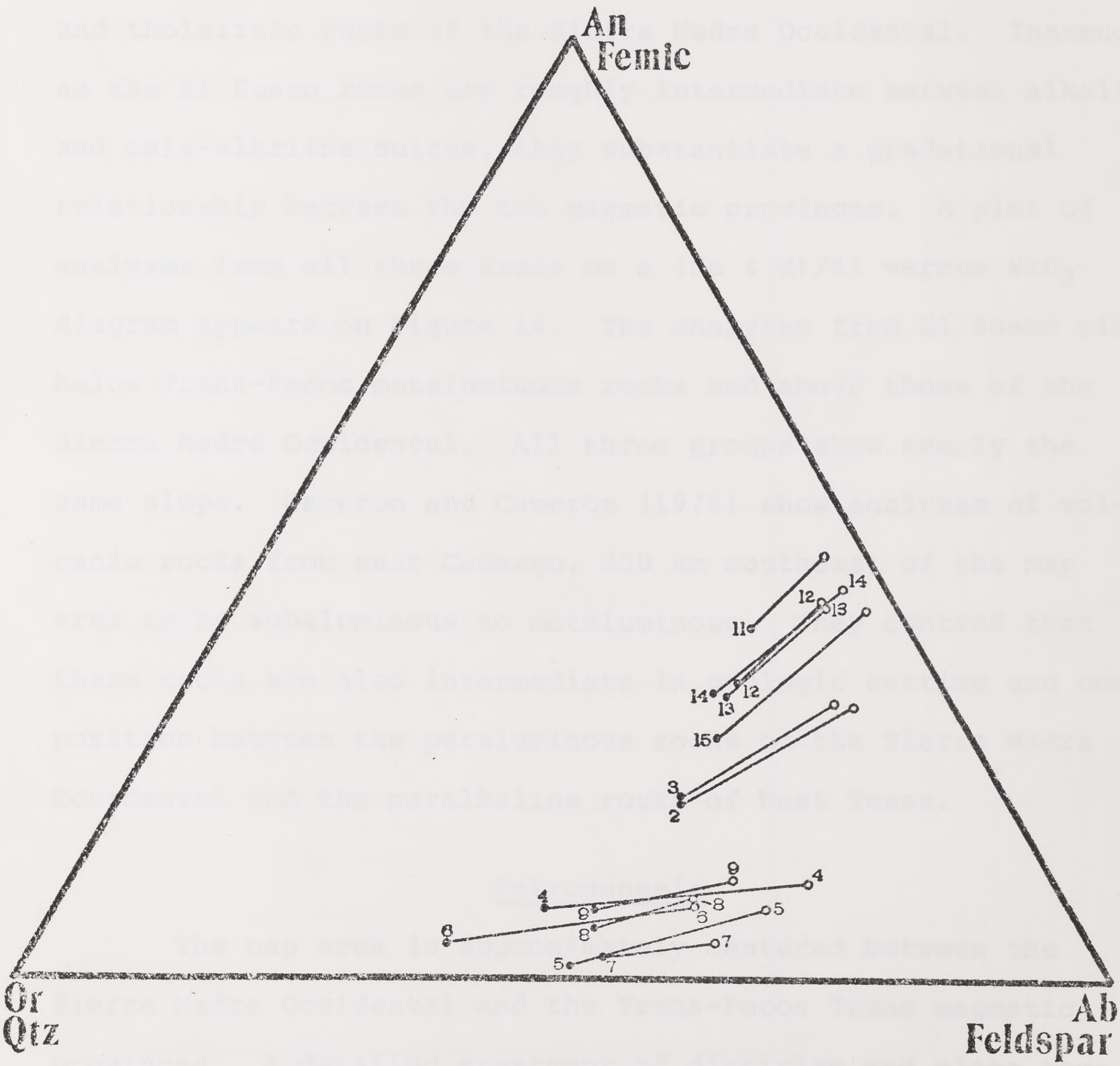


Figure 13. Larsen diagram for El Sueco volcanic suite.

Barker (in press) has documented that within the Trans-Pecos province there is a southwestward decrease in peralkalinity and increase in silica saturation toward the calc-alkaline and tholeiitic rocks of the Sierra Madre Occidental. Inasmuch as the El Sueco rocks are roughly intermediate between alkalic and calc-alkaline suites, they substantiate a gradational relationship between the two magmatic provinces. A plot of analyses from all three areas on a (Na & K)/Al versus SiO_2 diagram appears on Figure 14. The analyses from El Sueco plot below Trans-Pecos metaluminous rocks and above those of the Sierra Madre Occidental. All three groups show nearly the same slope. Cameron and Cameron (1976) show analyses of volcanic rocks from near Camargo, 200 km southeast of the map area to be subaluminous to metaluminous. They contend that these rocks are also intermediate in geologic setting and composition between the peraluminous rocks of the Sierra Madre Occidental and the peralkaline rocks of West Texas.

Petrogenesis

The map area is approximately centered between the Sierra Madre Occidental and the Trans-Pecos Texas magmatic provinces. A detailed treatment of diapirism and plate tectonics and their different means of magma generation is beyond the scope of this paper. To determine petrogenesis of the El Sueco rocks it is critical to decide to which province

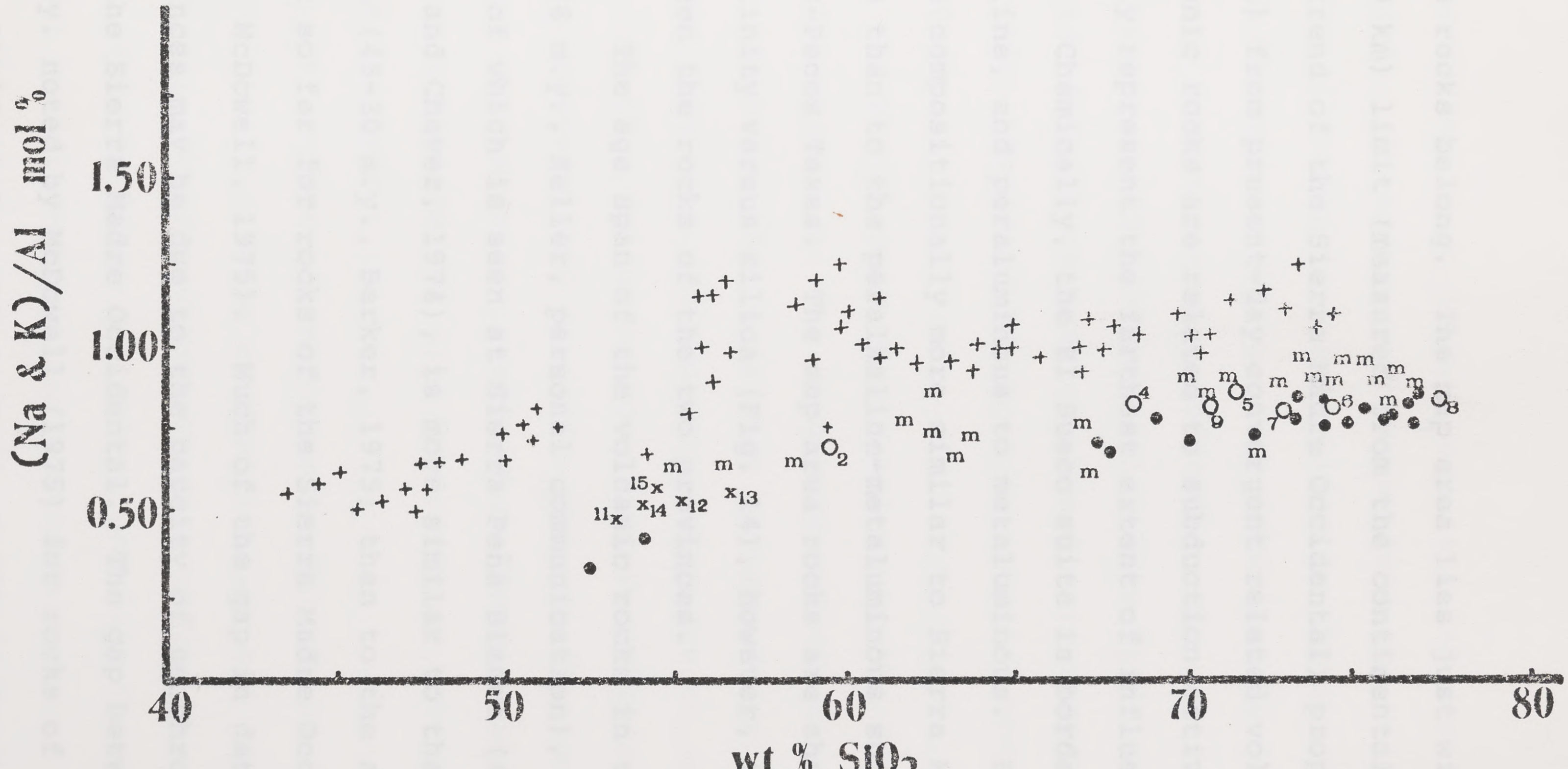


Figure 14. Diagram plotting alkalinity versus silica. Plus signs indicate alkaline rock analyses from Trans-Pecos Texas; m's represent metaluminous analyses from the same area (from Barker, in press); solid dots represent chemical analyses of rocks from Sierra Madre Occidental near Durango (from Swanson 1974 and Waitt 1970); circles and x's represent peraluminous and metaluminous rock analyses respectively from El Sueco. Numbers refer to list of rocks in Table 2.

these rocks belong. The map area lies just within the 600 mi (1000 km) limit (measured from the continental margin across the trend of the Sierra Madre Occidental) proposed by Gilluly (1971) from present-day convergent related volcanism. If the volcanic rocks are related to subduction activity, they very likely represent the farthest extent of influence of the zone.

Chemically, the El Sueco suite is borderline calc-alkaline, and peraluminous to metaluminous. By these standards it is compositionally more similar to Sierra Madre Occidental rocks than to the peralkaline-metaluminous suite of rocks in Trans-Pecos Texas. The map area rocks are shown on a plot of alkalinity versus silica (Fig. 14), however, to be gradational between the rocks of the two provinces.

The age span of the volcanic rocks in the map area (43-28 m.y., Keller, personal communication), the lower portion of which is seen at Sierra Peña Blanca (44-37 m.y., Alba and Chavez, 1974), is more similar to that of Trans-Pecos rocks (45-30 m.y., Barker, 1975) than to the age span determined so far for rocks of the Sierra Madre Occidental (31-23 m.y., McDowell, 1975). Much of the gap in dates between provinces may be due to the paucity of geochronologic data for the Sierra Madre Occidental. The gap between 28.5 and 23 m.y. noted by McDowell (1975) for rocks of the Sierra Madre Occidental may have begun to close (as he predicted it might). According to Cameron and Cameron (1976) volcanism was occurring 23 to 26 m.y. ago near Camargo in southeastern Chihuahua. Moreover, some dates from the Majalca area (area 28, Fig. 1) which presumably lies in the Sierra Madre Occidental volcanic province, are approximately 41 m.y. (McDowell, personal communication), indicating the age span for rocks of this province may have stretched from 31-23 to 41-23 m.y. As more age determinations from the Sierra Madre Occidental have been made, the trend has been to increase the known span of volcanism.

If the El Sueco rocks belong to the Sierra Madre Occidental province (as the chemistry and distribution of the rocks suggest), they eliminate any age differences between the two provinces and show that they are at least time equivalent. If they belong to the Trans-Pecos Texas province they show a compositional gradation between the two provinces. If the two provinces are gradational, magma generation by the different systems may also have some as yet unknown gradational features.

Any scheme of petrogenesis for the El Sueco rocks must explain the four major compositionally and texturally-defined sequences: the rhyolitic ash-flow tuffs, the andesitic lava flows, the rhyolitic intrusions and lava flows, and the bimodal basaltic-rhyolitic volcanism.

Rhyolitic ash-flow tuff of the Sierra Madre Occidental has been interpreted as resulting from partial melting of crustal rocks, specifically, remelting of Mesozoic-Early Tertiary batholithic basement, by rising basaltic magma (Swanson, 1974, Henry, 1975; and Keizer, 1973). Variations in composition of the rhyolitic rocks across the Sierra Madre Occidental apparently represent either differences in compositions of the rocks undergoing anatexis, or more crustal involvement eastward. In general, the El Sueco rocks continue the chemical trend seen in the cross-section of the Sierra Madre Occidental from Mazatlán to Durango. The rhyolitic ash-flow tuff of the map area probably represents partial fusion of crustal rocks.

The flows of the Rancho El Agate tholeiitic andesite probably represent the result of mixing of a rising basaltic magma with silicic components. Fritted feldspars are common in many intermediate to mafic rocks in tectonically active areas throughout the world (Kuno, 1950; Sigurdsson, 1971; Al-Rawi and Carmichael, 1967). Identical phenocrysts have been identified in the older andesite and the Metates Basalt from the Durango area (Swanson, 1974).

The close association of andesitic rocks with convergent plate boundary regimes has long been recognized (Dickinson, 1962, 1970; Taylor and White, 1965; Dickinson and Hatherton, 1967; and Green and Ringwood, 1968). The originally basaltic magma that formed the Rancho El Agate tholeiitic andesite is considered to be the result of melting above the easternmost reaches of such a subduction regime.

The rhyolitic lava flows, flow domes, and plugs of the third sequence, like the rhyolitic ash-flow tuffs of the first, probably represent anatexis of crustal rocks. Nevertheless, it may be significant that following andesite, lavas of rhyolite-rhyodacite, then rhyolite composition were extruded. Similar patterns are related to differentiation of basaltic magmas.

The final sequence of bimodal basalt flow and rhyolite ash-flow tuff volcanism probably resulted from partial melting of crustal rocks by rising basalts. Such a mechanism has been proposed for bimodal basalt-rhyolite by numerous authors (Christiansen and Lipman, 1972; Cole, 1973; and Clark, 1960). Because the basalt is calc-alkaline (although borderline), it may have been derived from partial melting in the mantle above a subduction zone.

MINERAL DEPOSITS

Introduction

Chihuahua is one of the richest mineral provinces in Mexico, producing large amounts of lead, zinc, silver, uranium, manganese, and some gold, mercury, fluorite, and barite. Many types of commercial or once commercial mineral deposits occur in and near the map area. Fluorite, barite, and galena have been mined in the map area at least as recently as 1947. Active lead and silver mines operate just to the east of the map area; manganese mines are located 15 km west of El Sueco. Less than 50 km south of the map area is a uranium mine producing high-grade ore. Farther south is a large and famous lead-zinc-silver mining operation at Santa Eulalia, at the edge of Chihuahua City. Valuable agates and geodes are mined from volcanic rocks within the map area.

Distribution

Three major mineral belts trend northwest through Chihuahua (Fig. 15). The western belt produces gold and silver from altered volcanic rocks. The middle belt produces primarily silver, lead and zinc; the easternmost deposits are rich in fluorite and mercury minerals, with associated lead, zinc, and silver. In the middle and eastern belts,

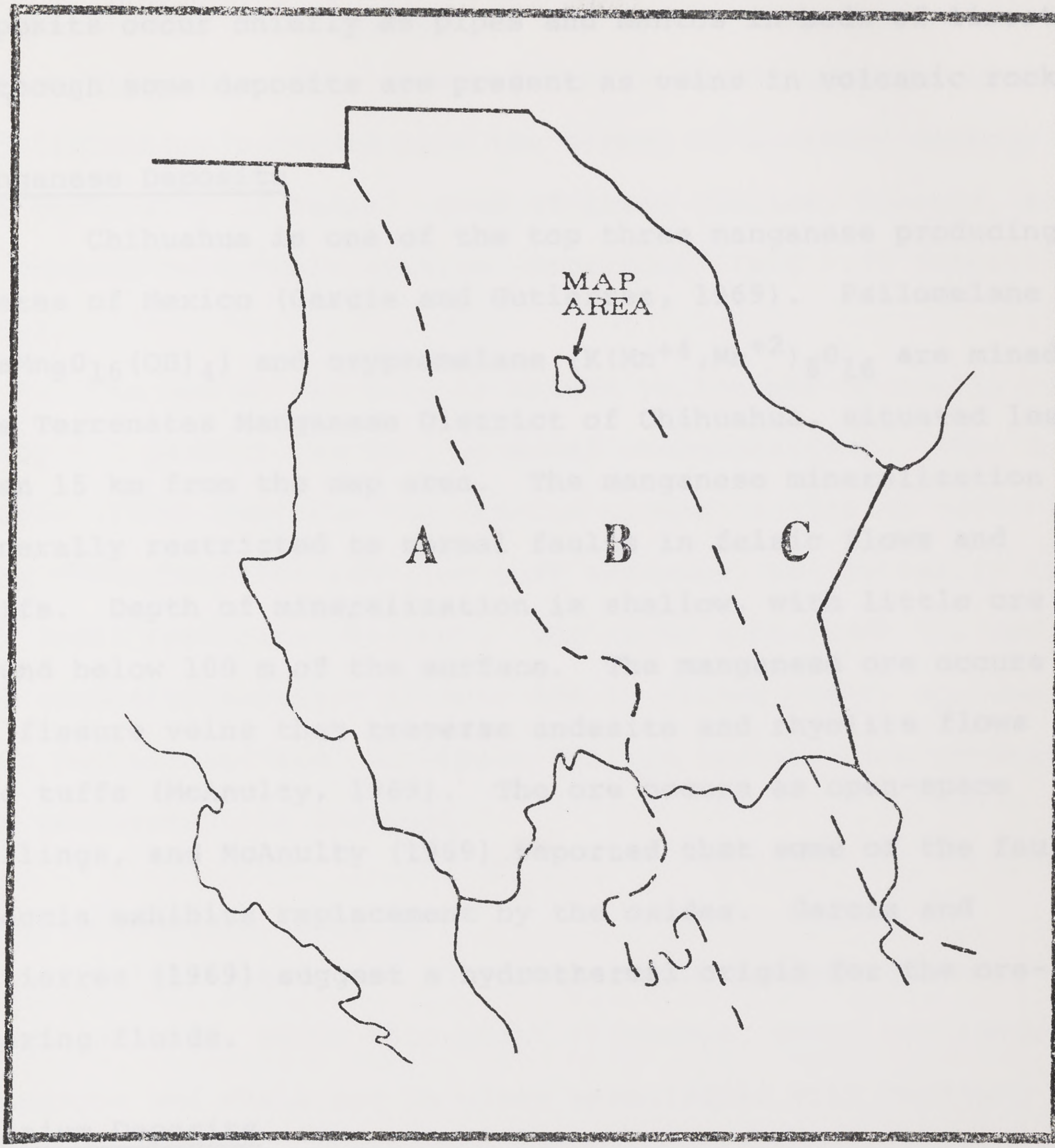


Figure 15. Map of Chihuahua showing three major belts of mineral deposits. Belt A has deposits of gold and silver ores. Belt B deposits are silver, lead and zinc ores. Belt C contains fluorine, mercury, lead, and zinc deposits (Modified from Ramirez, unpublished work).

deposits occur chiefly as pipes and mantos in beds of limestones, although some deposits are present as veins in volcanic rocks.

Manganese Deposits

Chihuahua is one of the top three manganese producing states of Mexico (Garcia and Gutierrez, 1969). Psilomelane ($BaMn_9O_{16}(OH)_4$) and cryptomelane ($K(Mn^{+4},Mn^{+2})_8O_{16}$ are mined in the Terrenates Manganese District of Chihuahua, situated less than 15 km from the map area. The manganese mineralization is generally restricted to normal faults in felsic flows and tuffs. Depth of mineralization is shallow, with little ore found below 100 m of the surface. The manganese ore occurs in fissure veins that traverse andesite and rhyolite flows and tuffs (McAnulty, 1969). The ore occurs as open-space fillings, and McAnulty (1969) reported that some of the fault breccia exhibits replacement by the oxides. Garcia and Gutierrez (1969) suggest a hydrothermal origin for the ore-bearing fluids.

Uranium Deposits

Uranium ore is mined from several areas in the Sierra Peña Blanca, less than 50 km south of the map area. The ore occurs as mantos, chimneys, veins, and veinlets in a sequence of Tertiary rhyolitic ash-flow tuffs overlying Cretaceous limestone strata. This ash-flow tuff sequence corresponds closely in age (Keller, personal communication) and lithology to the Liebres formation in the map area. Many samples of the Liebres formation were examined for traces of uranium, using a scintillometer borrowed from the Bureau of Economic Geology at the University of Texas. None of these samples, however, seem to contain detectable uranium (detection limit >.05 percent U_3O_8).

The ore at the mine is bright yellow and unusually rich (U_3O_8 > 2 percent, Garner, personal communication). Alba and Chavez (1974) describe the uranium mineralization as occurring throughout the ash-flow tuff sequence, but primarily in the Nopal Formation (Eocene). The rocks containing the ore are generally strongly altered and in places highly opaline. Both replacement and open-space filling textures are present, but replacement is dominant.

Silver-Lead-Zinc Deposits

Silver, lead, and zinc mines, some producing minor byproduct gold, occur throughout Chihuahua, where Cretaceous limestone and shale are in close association with Tertiary (?) intrusive igneous rocks. One of the largest occurrences is located near Chihuahua City, within the Santa Eulalia District. Thick-bedded, Cretaceous limestone (Aurora Formation) comprises most of Cerro de Santa Eulalia. The limestone is unconformably overlain by rhyolitic ash-flow tuffs and lava flows, similar to the oldest volcanic sequence present in the map area and at the Sierra Peña Blanca uranium mine. By 1966, the Santa Eulalia district had produced approximately 35 million tons of silver, lead, and zinc ore from replacement bodies in the limestone (Hewitt, 1966). The ore bodies are generally pipes and chimneys, although some veins and mantos are also present. Miners have mentioned that skarn deposits locally produce some ore; Hewitt further stated that contacts between limestone and felsic sills are favorable horizons for ore deposition. Spurr (1911) contended that ore solutions used fissures in the limestone as circulation channels.

Mineralization commonly includes pyrite, pyrrhotite, marmatite, galena, sphalerite, fluorite, calcite, dolomite, siderite, aragonite, quartz, hematite, limonite, and selenite. Rare associated minerals include native gold and silver, arsenopyrite, fayalite, ilvaite, knebelite, wollastonite, asbestos, "manganese salts," rhodochrosite, and vivianite.

Deposits Within Map Area

Geode Deposits

Siliceous geodes, less than 1 cm to more than 30 cm in diameter occur in the unit L ash-flow tuff member of the Liebres formation. The geodes are composed of chalcedony, quartz crystals (some amethystine and smoky), opal, calcite, hematite, and at least seven manganese oxide minerals (Finkelman and others, 1974). The chalcedony is length-slow, indicating either sulfate-rich alkaline waters, evaporitic conditions, or both (Folk and Pittman, 1971).

Some remnant devitrification spherulites occur in the ash-flow tuff, but these are uncommon. Geodes partially or wholly filled with finely laminated sediment, and nearly empty, thin-walled geodes are also present. The origin of the cavities for the geodes may have involved gas-charged spherulitic growth as proposed by Ross (1941). He contends that gases are retained in solution in the glass, and these gases begin to collect at centers of crystallization. As more gas collects, the cavity is enlarged, often deforming or obliterating the spherulite.

By some such process a multitude of cavities were formed in the lower part of Unit L. Alkaline waters dissolved large amounts of silica from the glassy igneous rock. Oxygen isotope studies by Land and Keller (Keller dissertation in progress) indicate the depositing waters became hotter through time, from about 40° C to over 65° C. This heating may have been caused by intrusion of Mesteño rhyolite flow domes which border the geode locality to the east and southwest. Periodic chemical changes, possibly rains which lowered the alkalinity, caused silica deposition in the cavities of the tuff. After or during geode formation, the faulting probably continued, evidenced by offset segments of some geodes.

The geodes are presently mined in an area no larger then 2 km^2, by blasting through overlying units to the productive zone, and digging the resistant geodes from the altered saprolite. Most of the geodes are mined from the basal vitrophyre of the gray ash-flow tuff. A more detailed treatment of the geodes and agates is being prepared by Keller.

Agate Deposits

Valuable nodules of agate are found in the Rancho El Agate tholeiitic andesite. Agate localities in the map area such as Coyamito, Ojo Laguna, and Aparejos are well-known internationally. The agates, which occur as amygdules in the tholeiitic andesite, are seldom larger than 10 cm in diameter, but nodules 40 cm across are known (Keller, personal communication). In thin section the agate is composed of length-fast chalcedony indicating a depositional process other than that involving alkaline water which formed the geodes in the Liebres formation, possibly hydrothermal water. In some agate nodules the chalcedony crystallized around large calcite (?) crystals which have since been leached away. Agates were previously mined more vigorously than at present, both by blasting and mining from the tholeiitic andesite rock and by recovery from lag gravel on the weathered surface and in the washes and gullies draining the area.

Fluorite-Barite Deposits

Just south of Rancho Agua Nueva, in the west-central portion of the map area, are numerous abandoned mine shafts and pits that yielded fluorite and possibly barite. The people at the rancho knew only of fluorite production; but barite is a common constituent of the tailings and ore piles. Small amounts of galena are also present. Gangue minerals include calcite, siderite, quartz, chalcedony, and hematite. These minerals occur as open-space fillings cementing breccias in fault zones in the Liebres formation. Mining followed the steep normal fault planes in the altered, silicified tuff.

Many of the faults in the vicinity of the mines radiate from large igneous centers (Carneros, El Dos, and Mesteño rhyolites), apparently due to doming. Investigations by the United States Geological Survey in the San Juan Mountains of Colorado have shown that most major ore deposits of the area are closely related to structural trends and hydrothermal activity of calderas (Lipman and Stevens, 1970). Although there are no calderas in the map area, the rhyolite plugs and flow domes close to the deposits appear to have controlled much of the structure of the area and may have been the source of the ores.

Silver-Lead-Zinc Deposits

In the eastern portion of the map area there exists a large network of silver, lead, and zinc mines. Section B of the Appendix lists the names of some of the mines, their owners, and the metals mined. Gutierrez and Gutierrez (1964) state that the Sierra de las Damas ore is found in mantos, chimneys, and vein deposits which have selectively replaced Cretaceous formations. The ore apparently favors the Albian Aurora Formation as a deposition site. Most of the mines in or near the map area are associated with small faults trending nearly perpendicular to the regional NNW-trend. These faults may have controlled the movement of ore-bearing fluids to the layer or area of deposition. Minerals identified by X-ray diffraction and in-hand specimen from ore and tailings piles include galena, chalcopyrite, sphalerite, calcite, quartz, hematite, limonite, selenite, and hydromagnesite.

Origin of the ores is problematical. Elston and others (1973) has shown that two important periods of base metal mineralization were contemporaneous with Tertiary volcanism in southwestern New Mexico and that volcanic areas are favorable grounds for prospecting. Flow-domes of Mesteño rhyolite crop out within several kilometers of some of the mines, and large vent areas have been identified within 25 km of the deposits. Xenoliths of granite from volcanic rocks to the west indicate siliceous plutons underlie at least some of the region. Such rocks may have provided the ore fluids.

GEOLOGIC HISTORY

Little is known about the Precambrian and Paleozoic history of central Chihuahua. Based on petrographic data and isotopic age studies on cobbles in a conglomerate beneath Lower Cretaceous (Albian) limestone, Denison and others (1970) contend that the region experienced rhyolitic volcanism in the Late Precambrian, and intense regional metamorphism, compression and some volcanism in the Permian period. According to Wiley and Muehlberger (1970) and Haenggi and Gries (1970), structural movement occurred in the Paleozoic Era along: 1) the "Texas Lineament" (see Fig. 15), the fault zone bounding the Diablo Platform on the west, 2) the Ouachita structural belt, and 3) along a zone of weakness trending N 40°-50° W in the northern Sierra de la Parra, northern Chihuahua. Haenggi and Gries contend these structured movements helped form the Chihuahua Trough which deepened during the Jurassic and Cretaceous periods, while accumulating sediments to a thickness of 3700 to 6500 m. Sometime between the Late Cretaceous (Senonian) and Late Eocene, the Chihuahua Trough was tilted to the east. Haenggi and Gries (1970) believe this may have been caused by a broad asymmetrical tilting of the center of the trough. However, DeFord (1969) contends that uplift of the Aldama Platform, west of the trough, caused the tilting and

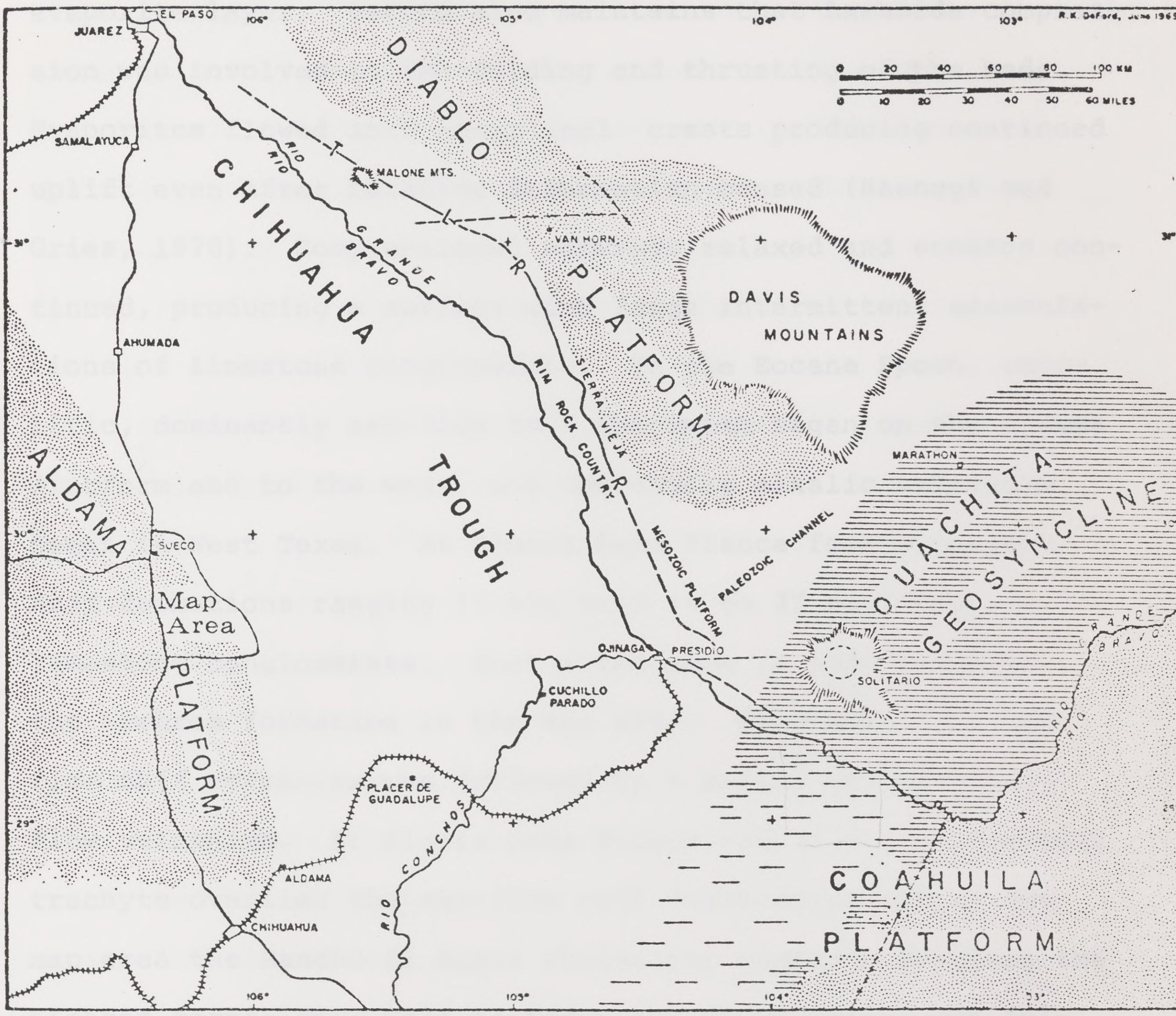


Figure 16. Modified after DeFord (1969). Tectonic framework of northeastern Chihuahua. TL: type locality of Texas lineament. RR: Rim Rock Fault. Volcanic rock covers most of the area of: Davis Mountains; southern part of Diablo platform on to Solitario; inferred extension of Ouachita geosyncline into Chihuahua.

induced the Cretaceous beds to slide eastward on a lubricating evaporite layer. DeFord also maintains that Laramide compression was involved in the folding and thrusting of the beds. Evaporites flowed into anticlinal crests producing continued uplift even after Laramide deformation ceased (Haenggi and Gries, 1970). Compressional stresses relaxed and erosion continued, producing a surface with large intermittent accumulations of limestone conglomerate. In the Eocene Epoch, rhyolitic, dominantly ash-flow tuff volcanism began on the Aldama Platform and to the west, and dominantly alkalic volcanism began in West Texas. At Sierra Peña Blanca four rhyolitic tuff formations ranging in age from 44 to 37 m.y. rest on limestone conglomerate. Such a sequence is also found in the Liebres formation in the map area. This period of ash-flow tuff volcanism was followed by a period of mafic lava flow volcanism. At Sierra Peña Blanca the 37.3 m.y. old Mesa trachyte overlies the ash-flow tuff formations, and in the map area the Rancho El Agate tholeiitic andesite overlies the Liebres formation. This second stage of volcanism was followed by a stage of rhyolitic volcanism which in the map area includes the Gallego, Mesteño, Carneros and El Dos rhyolite lava flows. The Carneros, El Dos, and Mesteño units all have associated plugs and flow domes, and are responsible for the doming and resultant fault patterns seen in the southwestern portion of the map area. After a hiatus of approximately

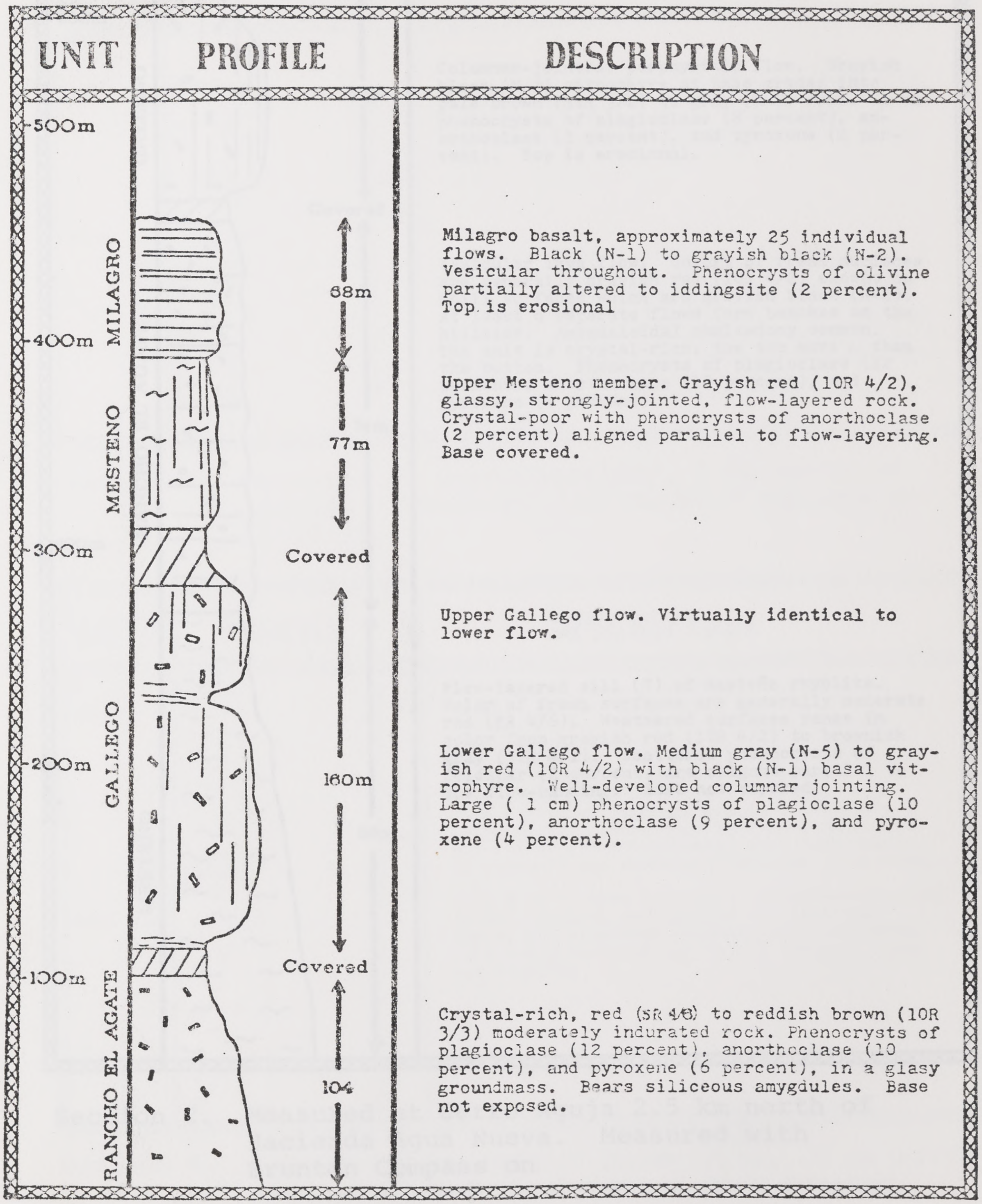
6 m.y., a fourth and probably final stage of basaltic lava flow and rhyolitic ash-flow tuff volcanism (the Milagro basalt) occurred. Included in the third stage, but possibly continuing through the fourth stage and after, are flow domes of Mesteño rhyolite which seem to be aligned with major Basin and Range-type faults that truncated the mafic flows of the fourth stage. A potassium-argon age-determination on one of the flow domes indicates that it belongs to the third stage of volcanism (Keller, personal communication); however, some flow domes may be younger. Most volcanism in the region ceased before major Basin and Range faulting began in the late Oligocene and early Miocene. Rio Grande rifting in New Mexico and possibly in Chihuahua also began at this time. Chapin and Seager (1975) place the date of initial rifting at between 31 and 28 mybp. In Chihuahua, large normal faults trending north-northwest cut both carbonate and volcanic rocks, providing immense horsts and grabens which formed ranges and basins respectively. Haenggi and Gries (1970) summarized the remaining history:

> Late Cenozoic erosion filled the grabens and a Pleistocene integrated drainage system developed between these bolson fills, crossing the uplift blocks at the fill-covered structurally low areas. Movement along the normal faults has continued into the Quaternary period.

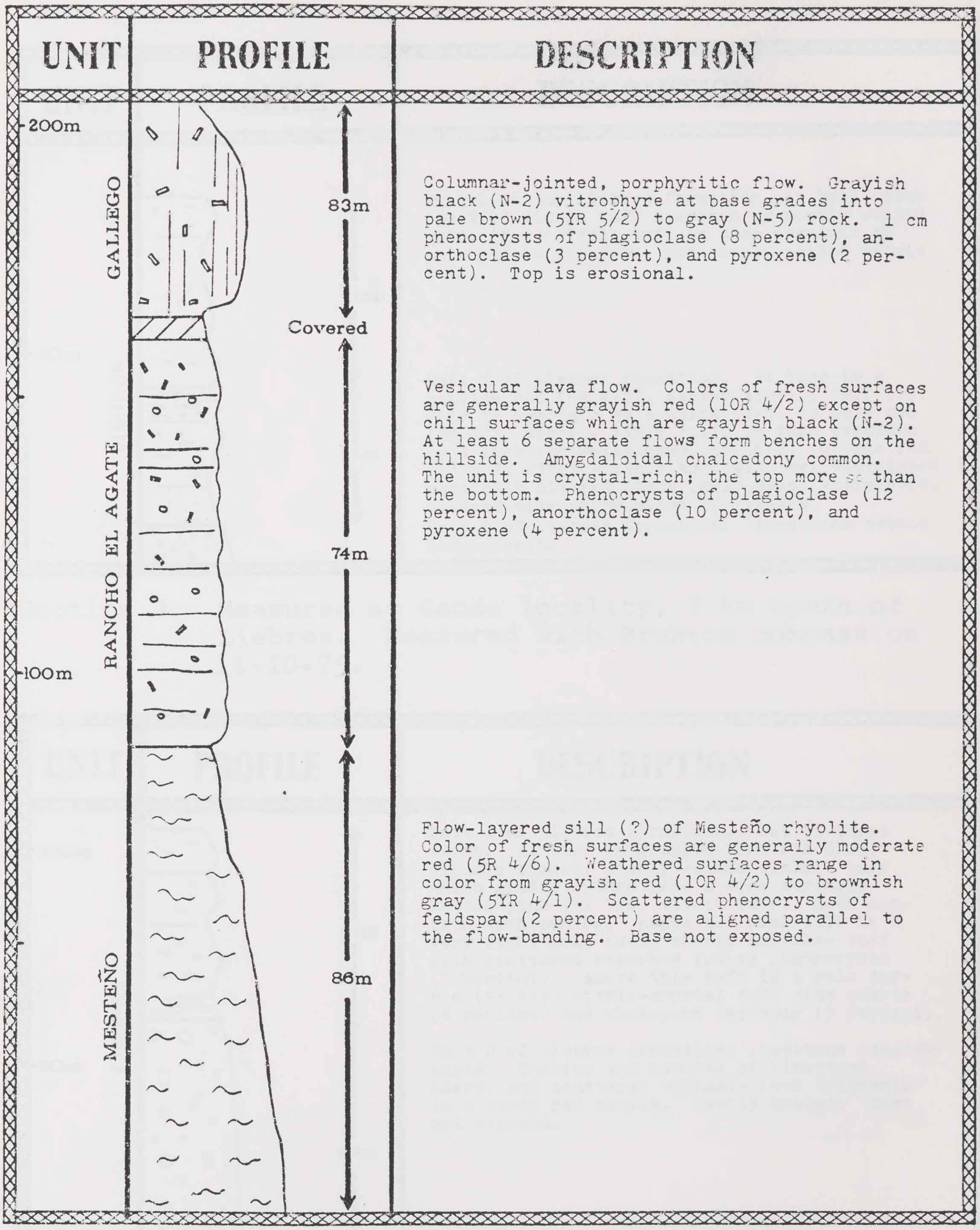
APPENDICES

APPENDIX A

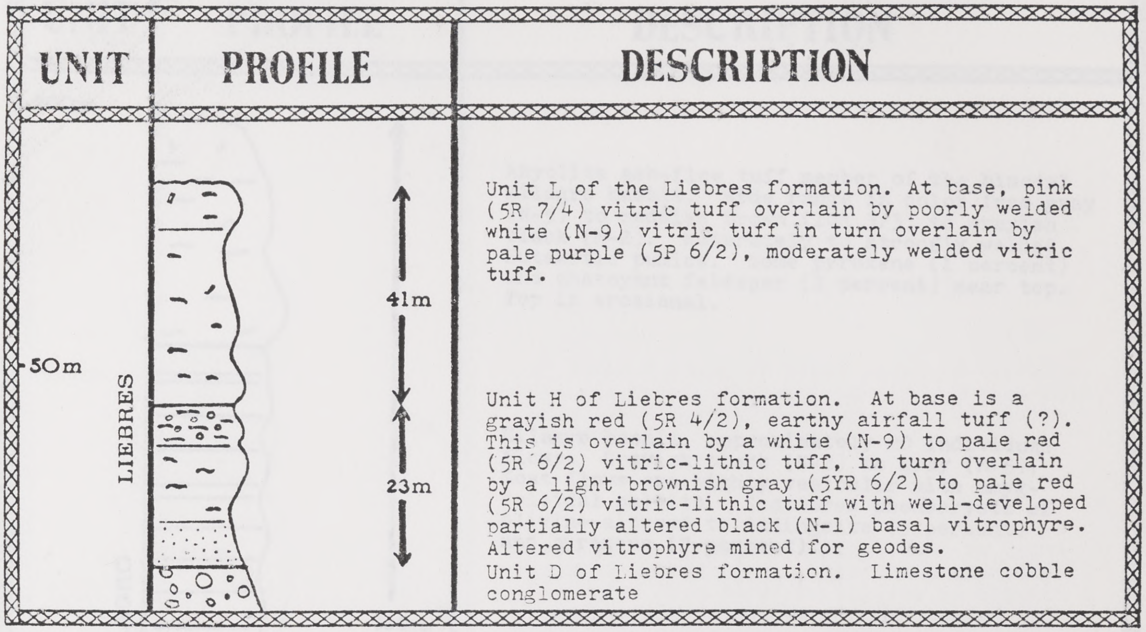
Measured Sections



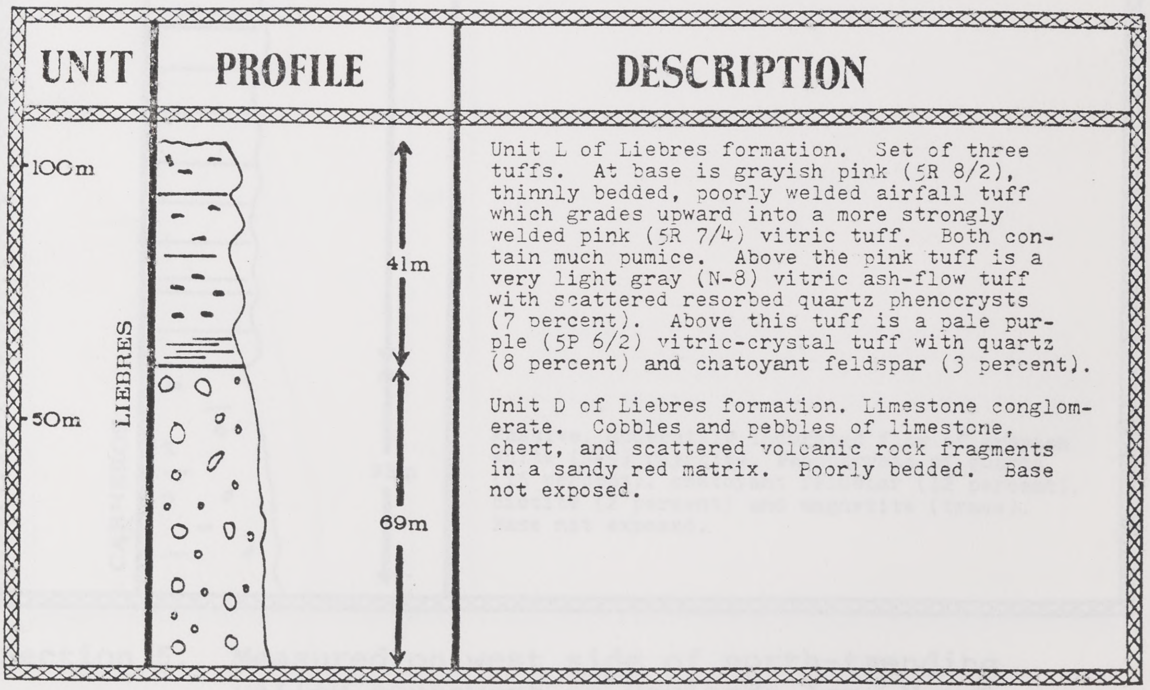
Section 1. Columnar section measured at Cerro Gallego 6 km southeast of El Sueco. Measured with Brunton compass on 10-10-75.



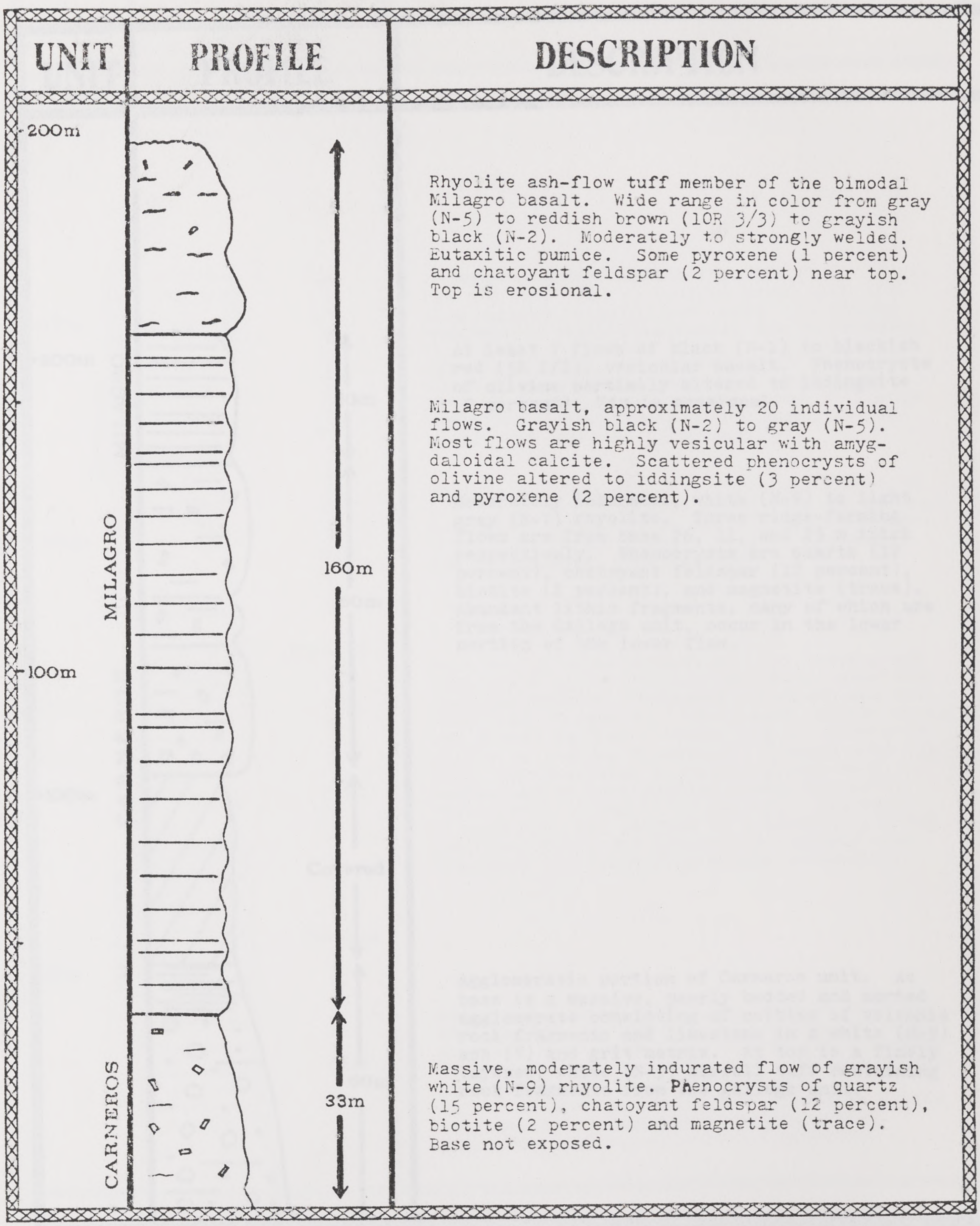
Section 2. Measured at Cerro Aguja 2.5 km north of Hacienda Agua Nueva. Measured with Brunton Compass on



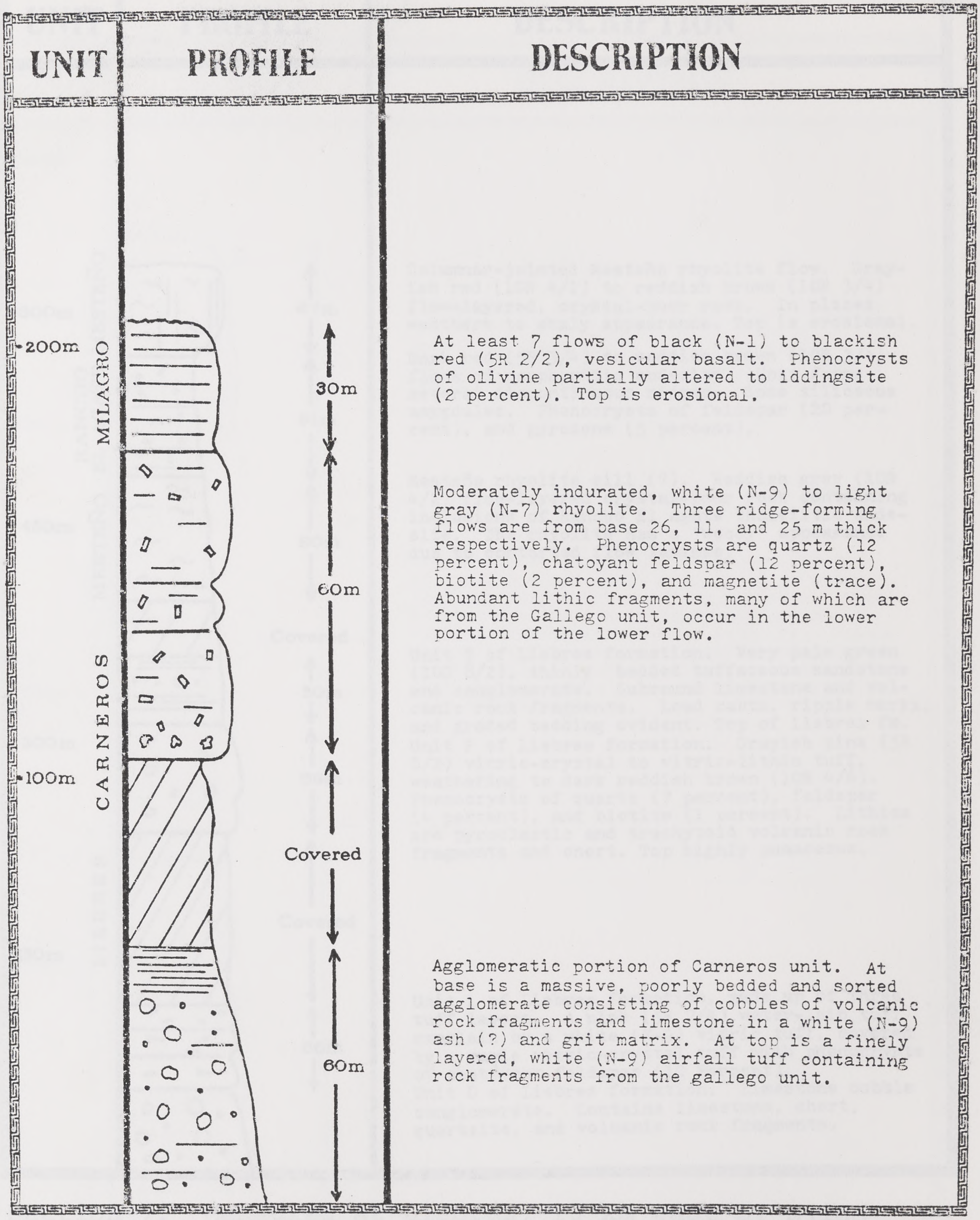
Section 3. Measured at Geode locality, 7 km south of Liebres. Measured with Brunton compass on 11-10-75.



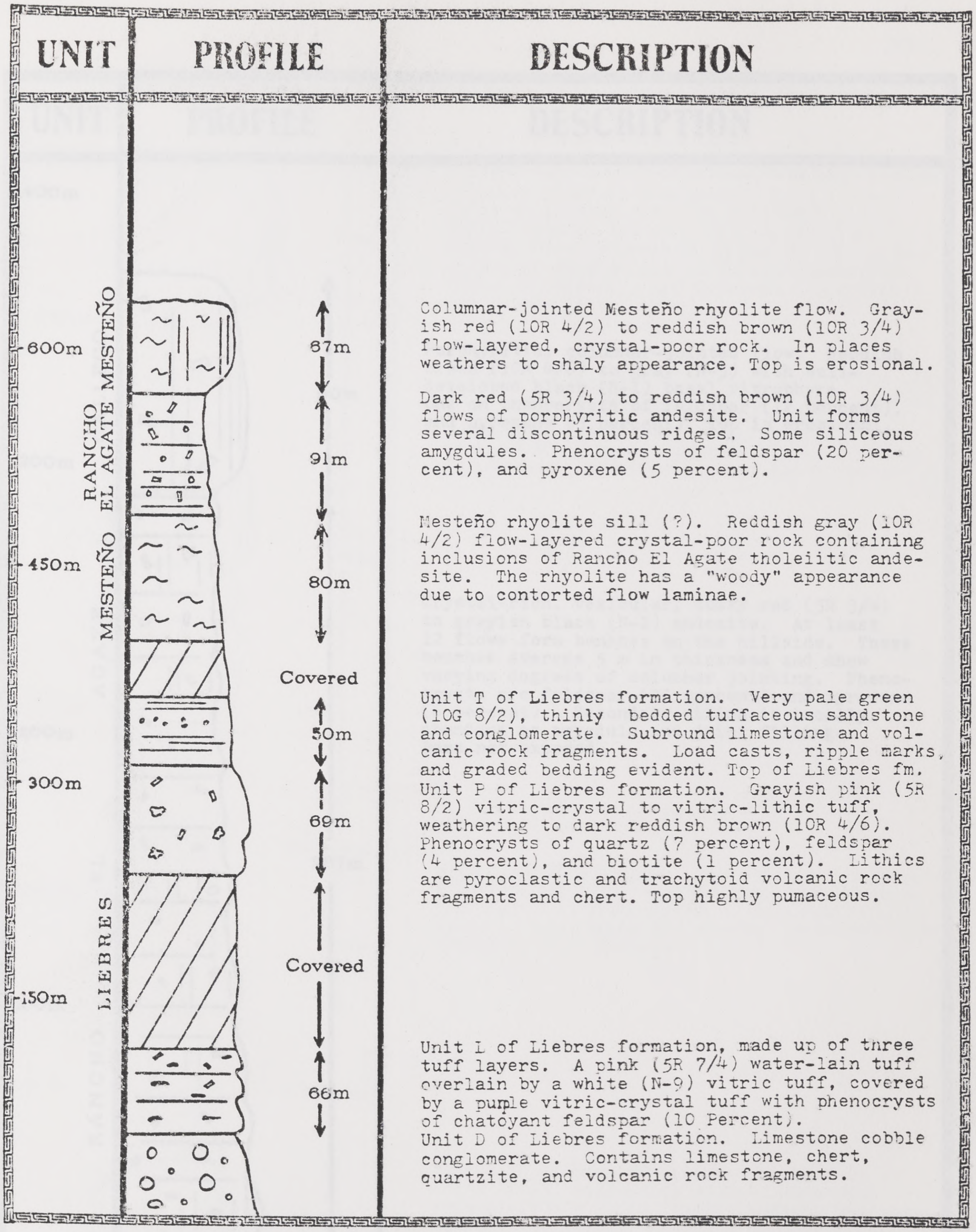
Section 4. Measured 2 km east of Alamo Pozo, 12 km northeast of El Sueco. Measured with Brunton compass on 11-19-75.



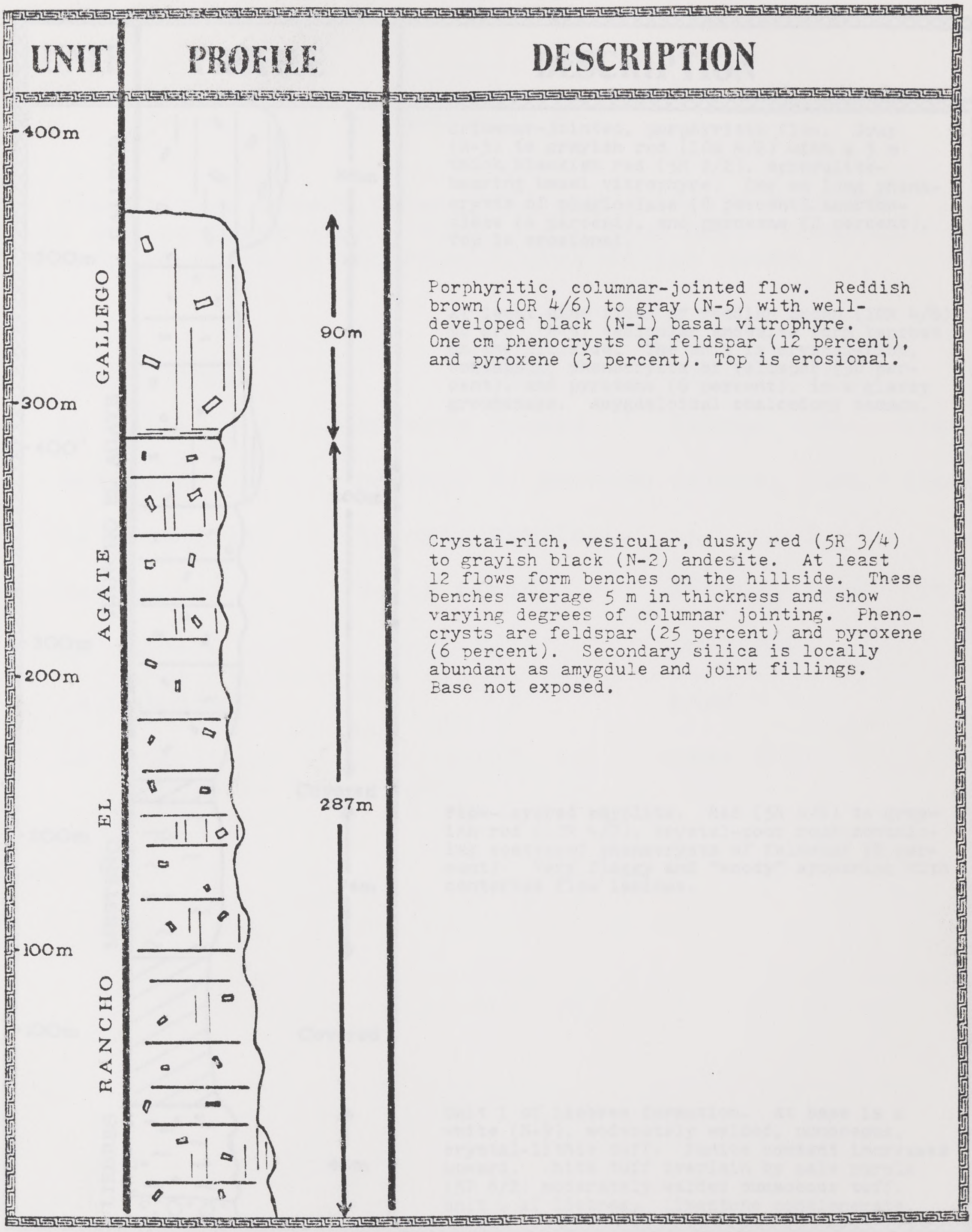
Section 5. Measured on west side of north-trending valley southwest of Hacienda Agua Nueva; 1 km south of hairpin turn in main dirt road to Rancho El Milagro. Measured with Brunton compass on 1-7-76.



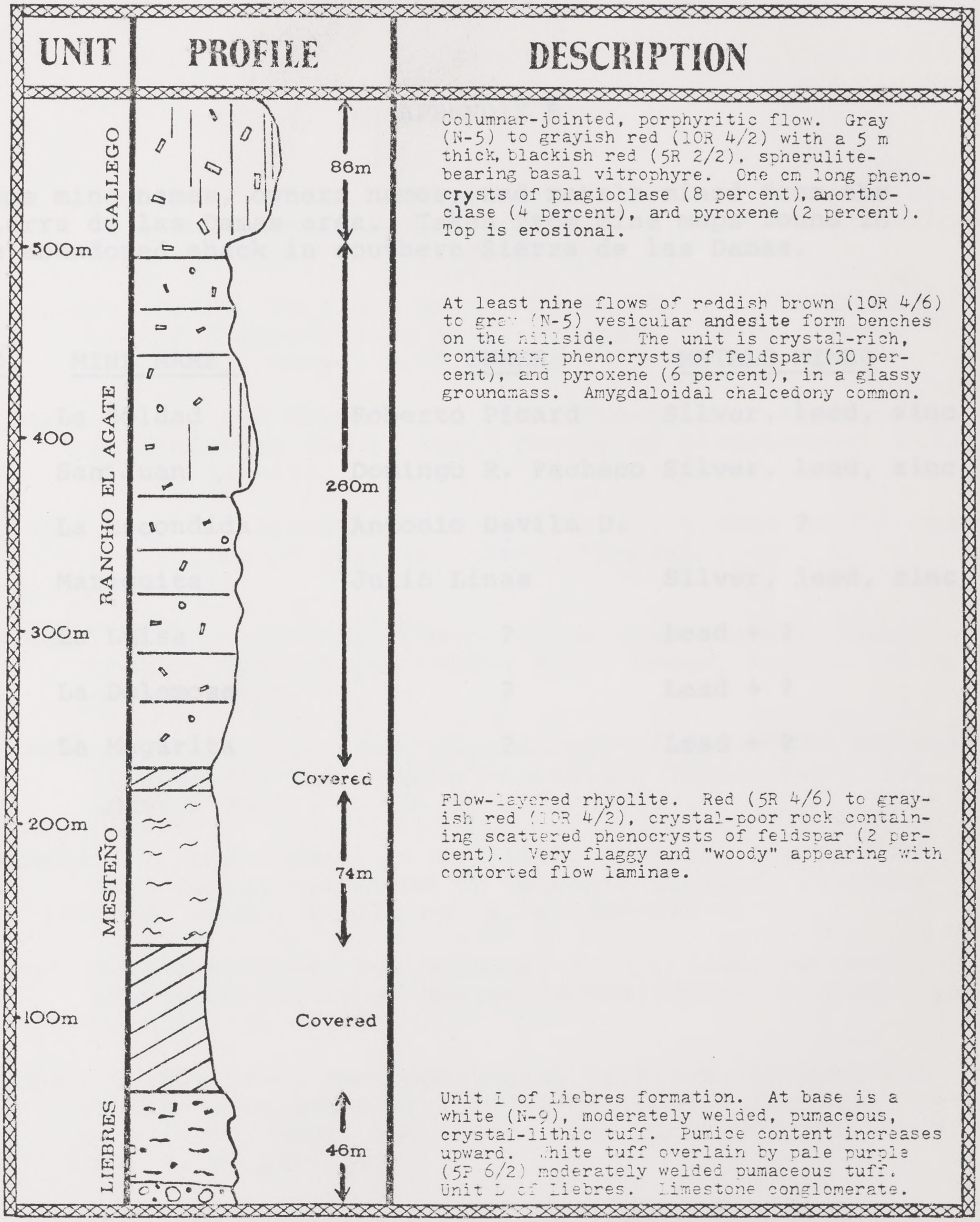
Section 6. Measured 3 km northeast of Rancho El Milagro. Measured with Brunton compass on 1-7-76.



Section 7. Measured at Liebres, 10 km east of Ejido Esperanza. Measured with Brunton compass on 1-8-76.



Section 8. Measured at Rancho El Agate. Measured with Brunton compass on 1-9-76.



Section 9. Measured 1 km south of Rancho Las Tarabillas, 12 km east of El Sueco. Measured with Brunton compass on 1-9-76.

APPENDIX B

Some mine names, owners names, and metals mined from the Sierra de las Damas area. Taken from mine maps found in an abandoned shack in southern Sierra de las Damas.

NO.	MINE NAME	OWNER	METALS MINED
1	La Soldad	Roberto Picard	Silver, lead, zinc
2	San Juan	Domingo R. Pacheco	Silver, lead, zinc
3	La Escondida	Antonio Davila D.	?
4	Mariquita	Julio Linas	Silver, lead, zinc
5	La Luisa	?	Lead + ?
6	La Dolomosa	?	Lead + ?
7	La Magarita	?	Lead + ?

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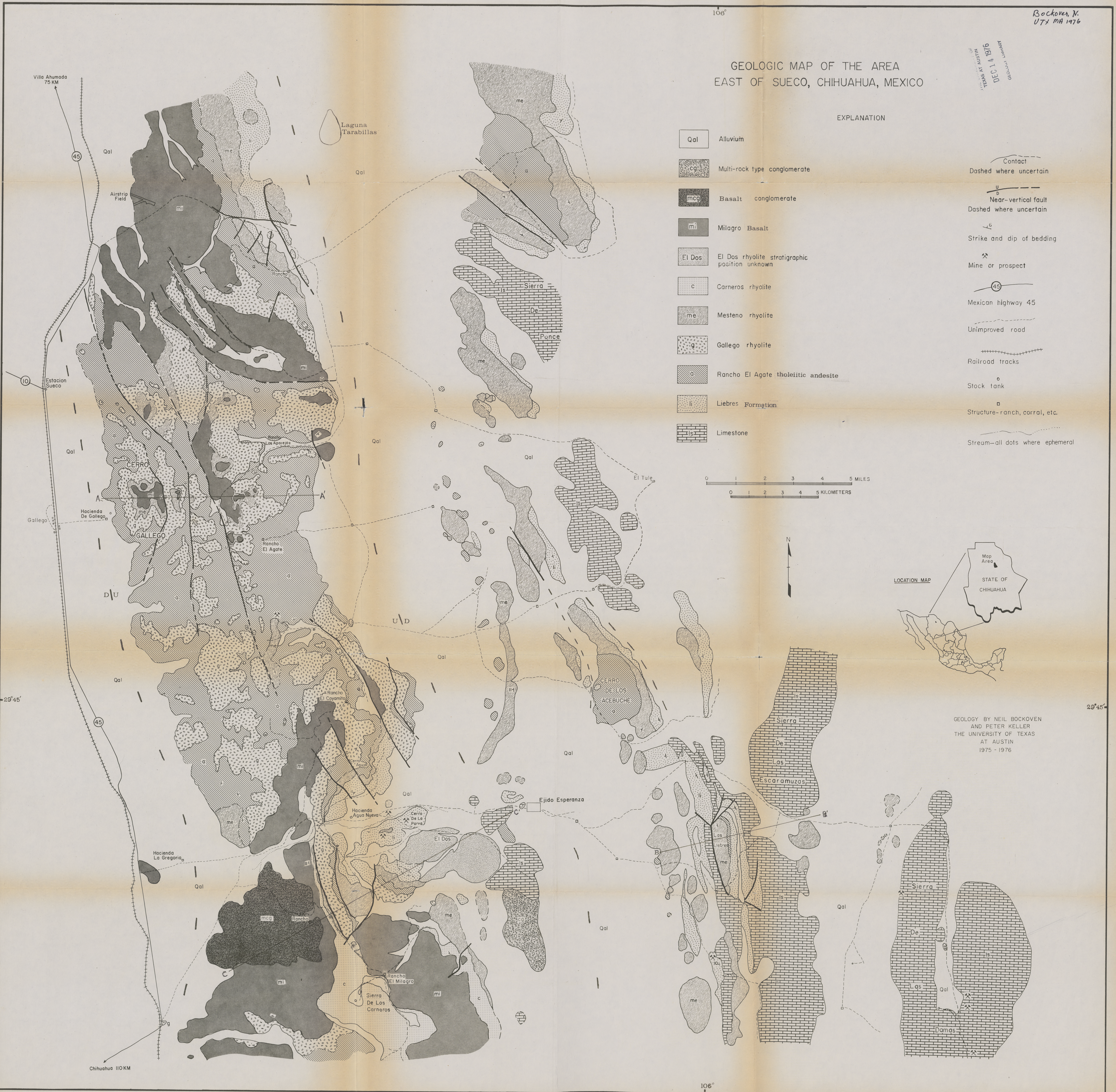
GEOLOGIC MAP OF THE AREA
EAST OF SUECO, CHIHUAHUA, MEXICO
Bockoven, N.
UTx MA 1976
DEC 14 1976
EXPLANATION
Qal Alluvium
cg Multi-rock type conglomerate
mcg Basalt conglomerate
mi Milagro Basalt
El Dos El Dos rhyolite stratigraphic position unknown
c Carneros rhyolite
me Mesteno rhyolite
g Gallego rhyolite
a Rancho El Agate tholeiitic andesite
li Liebres Formation
ls Limestone
Contact
Dashed where uncertain
Near-vertical fault
Dashed where uncertain
Strike and dip of bedding
Mine or prospect
Mexican highway 45
Unimproved road
Railroad tracks
Stock tank
Structure-ranch, corral, etc.
Stream-all dots where ephemeral
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
N
LOCATION MAP
Map Area
STATE OF CHIHUAHUA
GEOLOGY BY NEIL BOCKOVEN
AND PETER KELLER
THE UNIVERSITY OF TEXAS
AT AUSTIN
1975 - 1976
106°
29°45'
Villa Ahumada 75 KM
Laguna Tarabillas
Airstrip Field
Estacion Sueco
Hacienda De Gallego
Gallego
CERRO GALLEGO
Rancho Los Apareios
Rancho El Agate
Rancho El Coyomito
Hacienda Agua Nueva
Cerro De La Parva
El Dos
Ejido Esperanza
Hacienda La Gregoria
Rancho El Milagro
Sierra De Los Carneros
Chihuahua 110 KM
Sierra De Punce
El Tule
CERRO DE LOS ACEBUCHE
Sierra De Las Escaramuzos
Sierra De Las Damas
Las Liebres
A
A'
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B'
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45
10

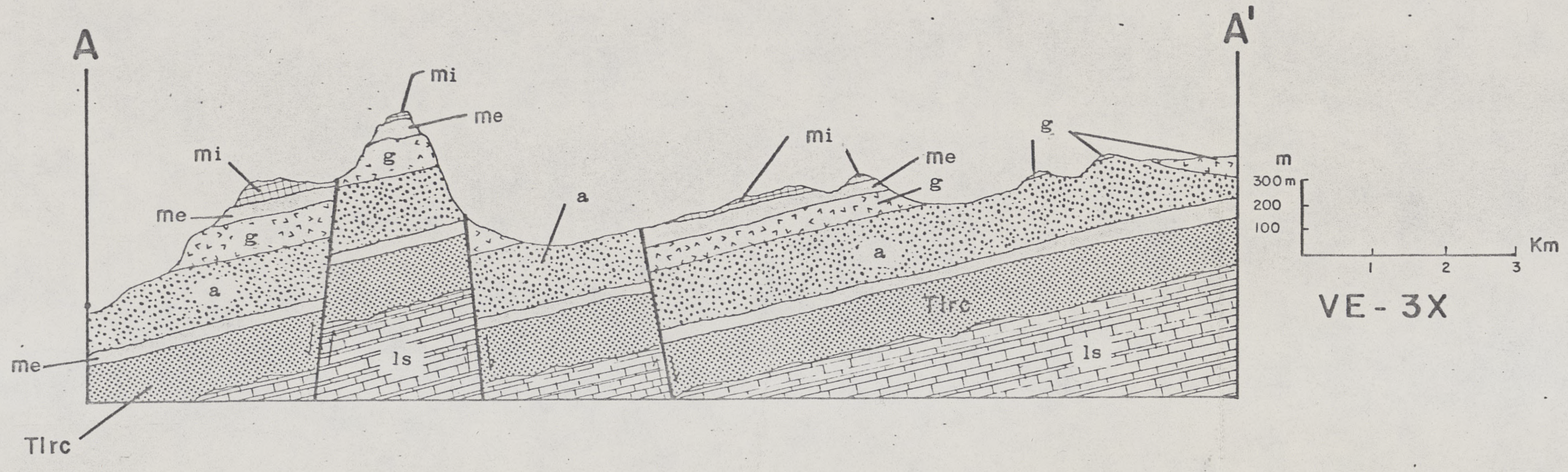
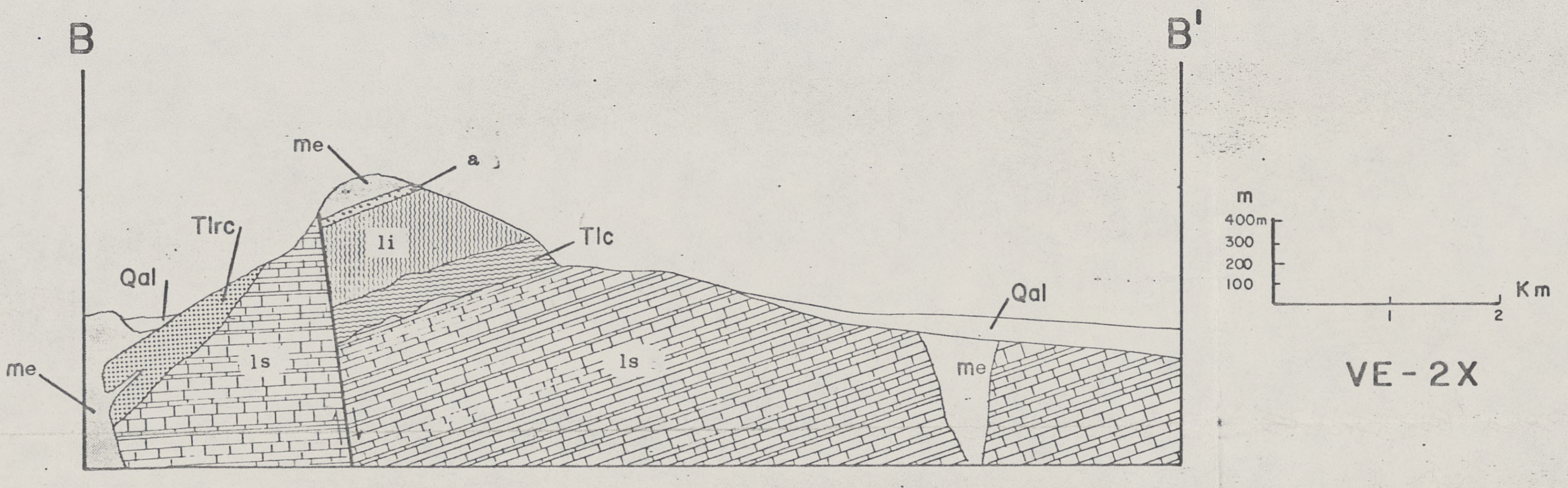


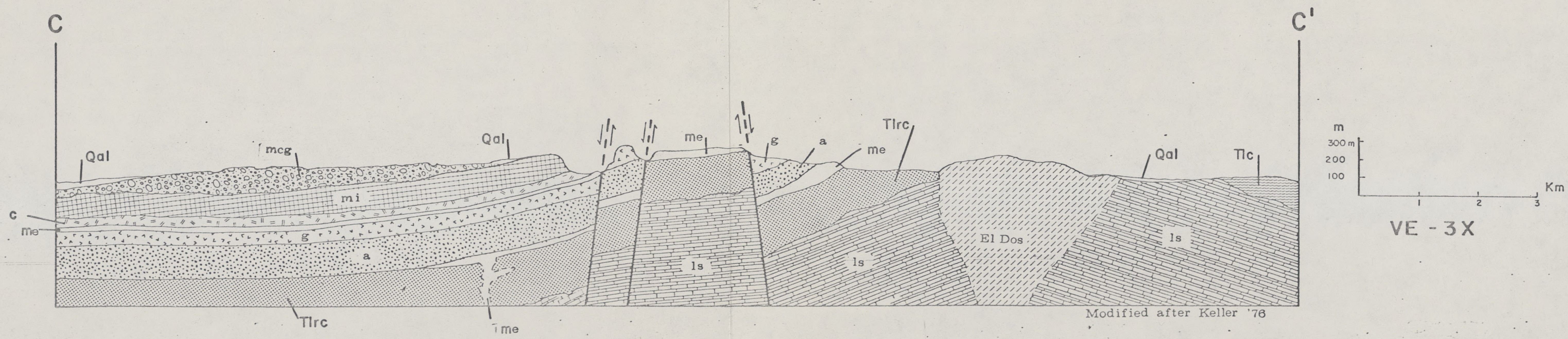
Plate 2

SIERRA GALLEGO AREA

Chihuahua, Mexico

CROSS SECTIONS





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